Higgs Searches at the Tevatron

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for the DØ and CDF collaborations

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- Introduction & the Tevatron
- Beyond Standard Model Higgs
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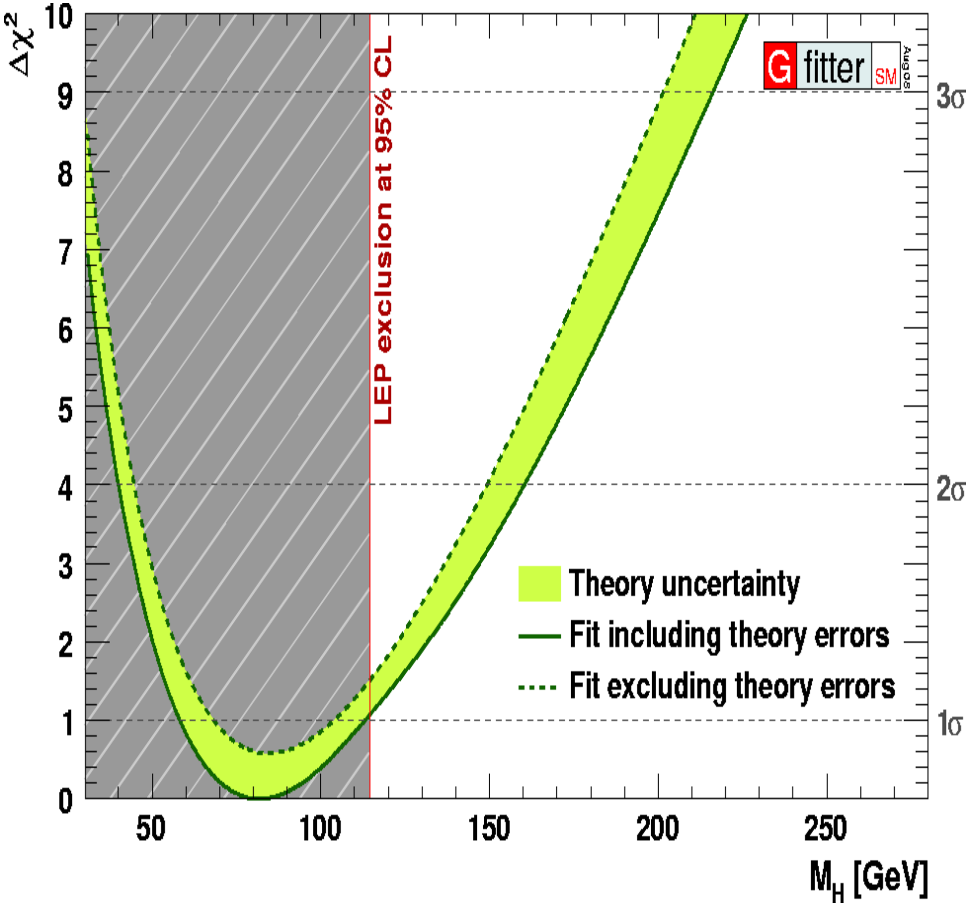
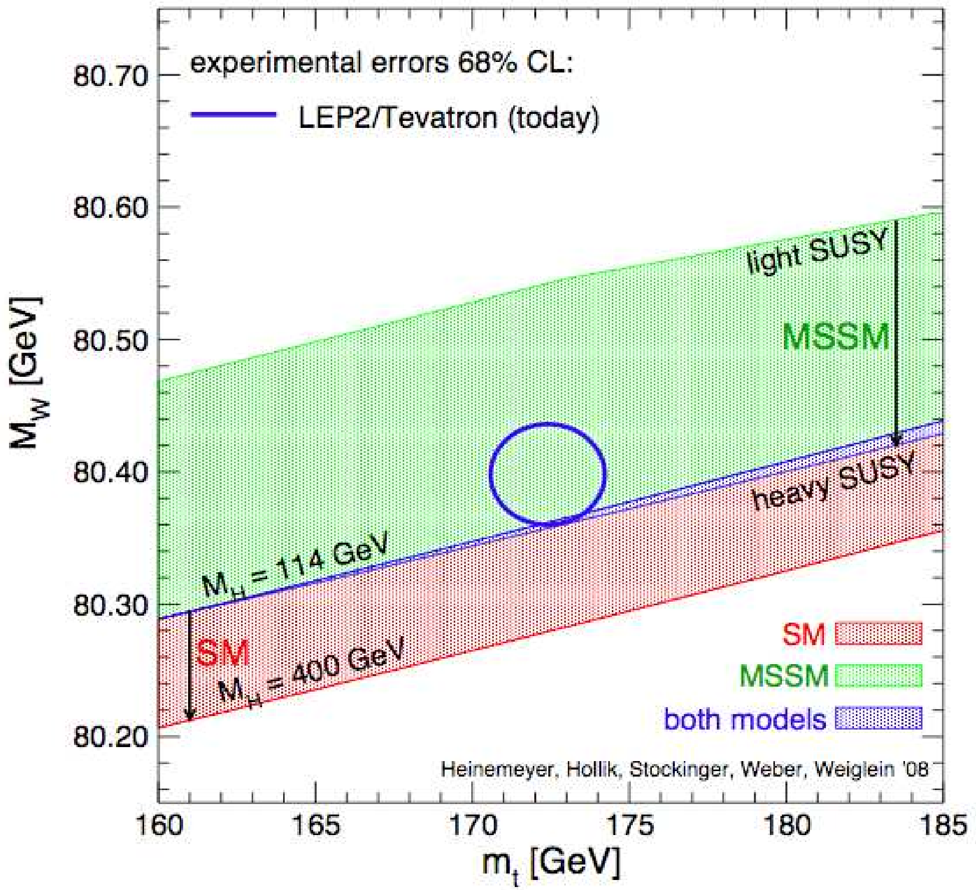
  - fermiophobic Higgs
- Standard Model Higgs
  - low mass
  - high mass
- Combination

Introduction

Higgs mechanism is responsible for breaking is prime suspect for electroweak symmetry breaking and provides a way for the fermions to obtain mass

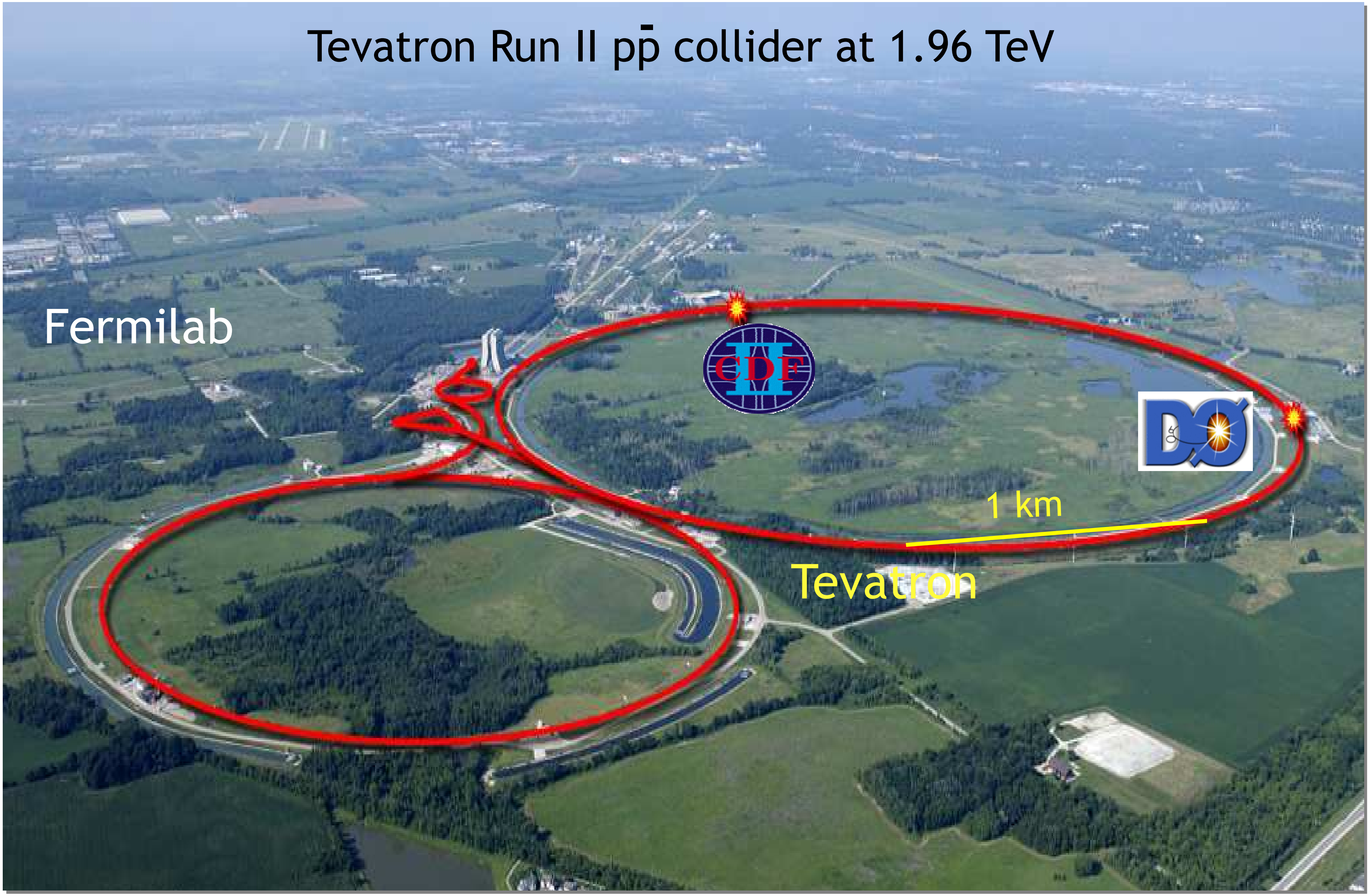




If Higgs is Standard Model Higgs, Tevatron is looking in the right place

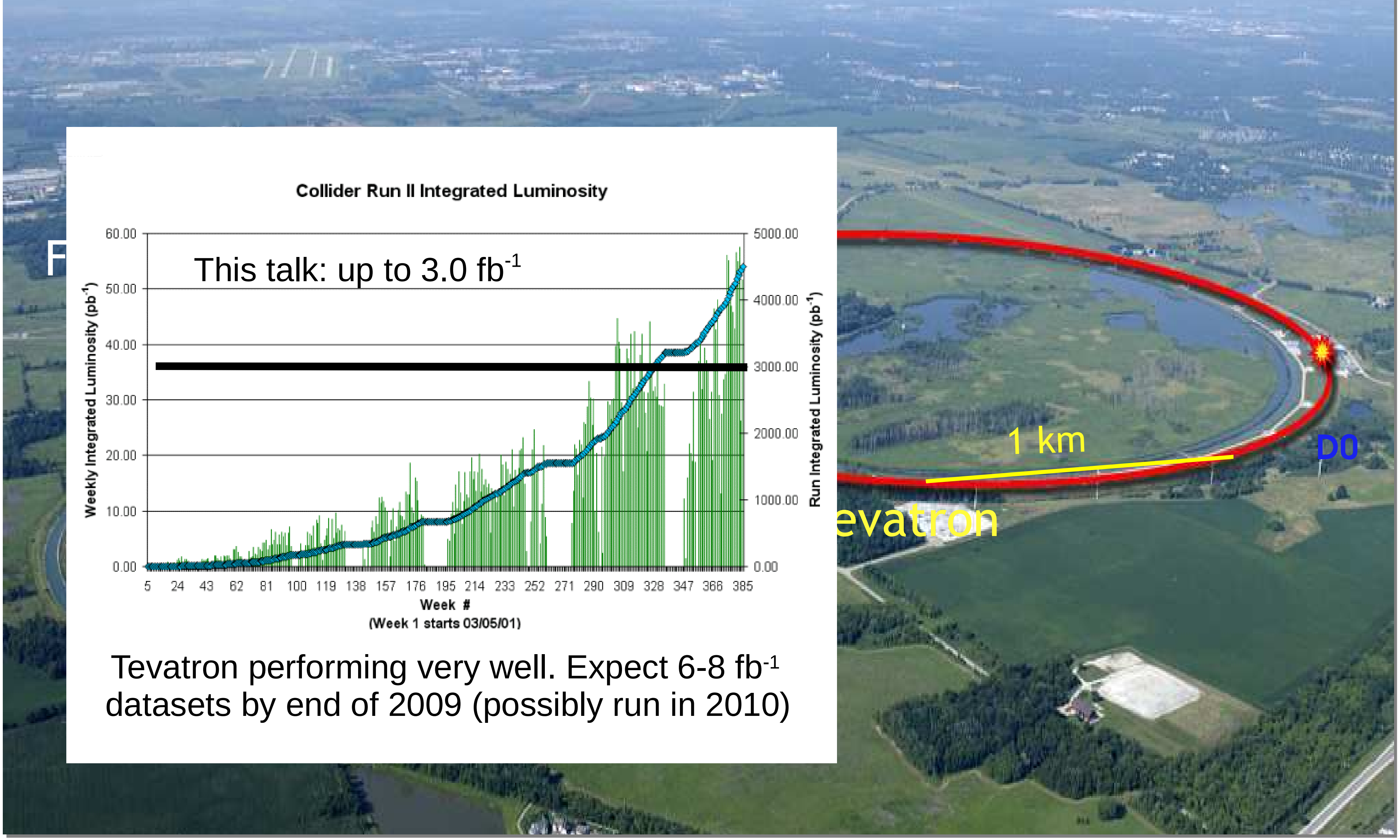
But we should also look for Supersymmetric Higgs.

The Tevatron at Fermilab



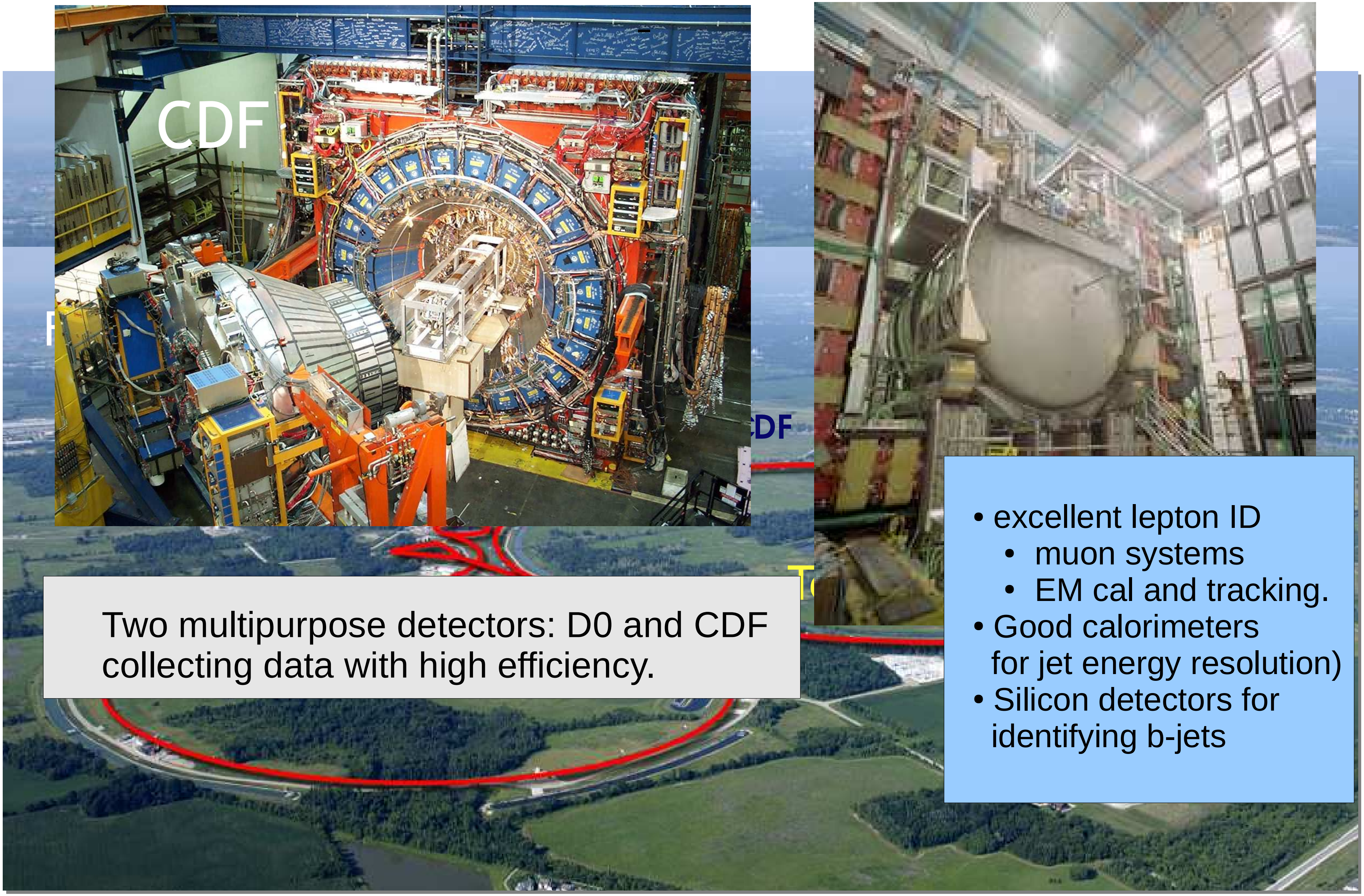
The Tevatron at Fermilab

Tevatron Run II $p\bar{p}$ collider at 1.96 TeV



Tevatron performing very well. Expect 6-8 fb^{-1} datasets by end of 2009 (possibly run in 2010)

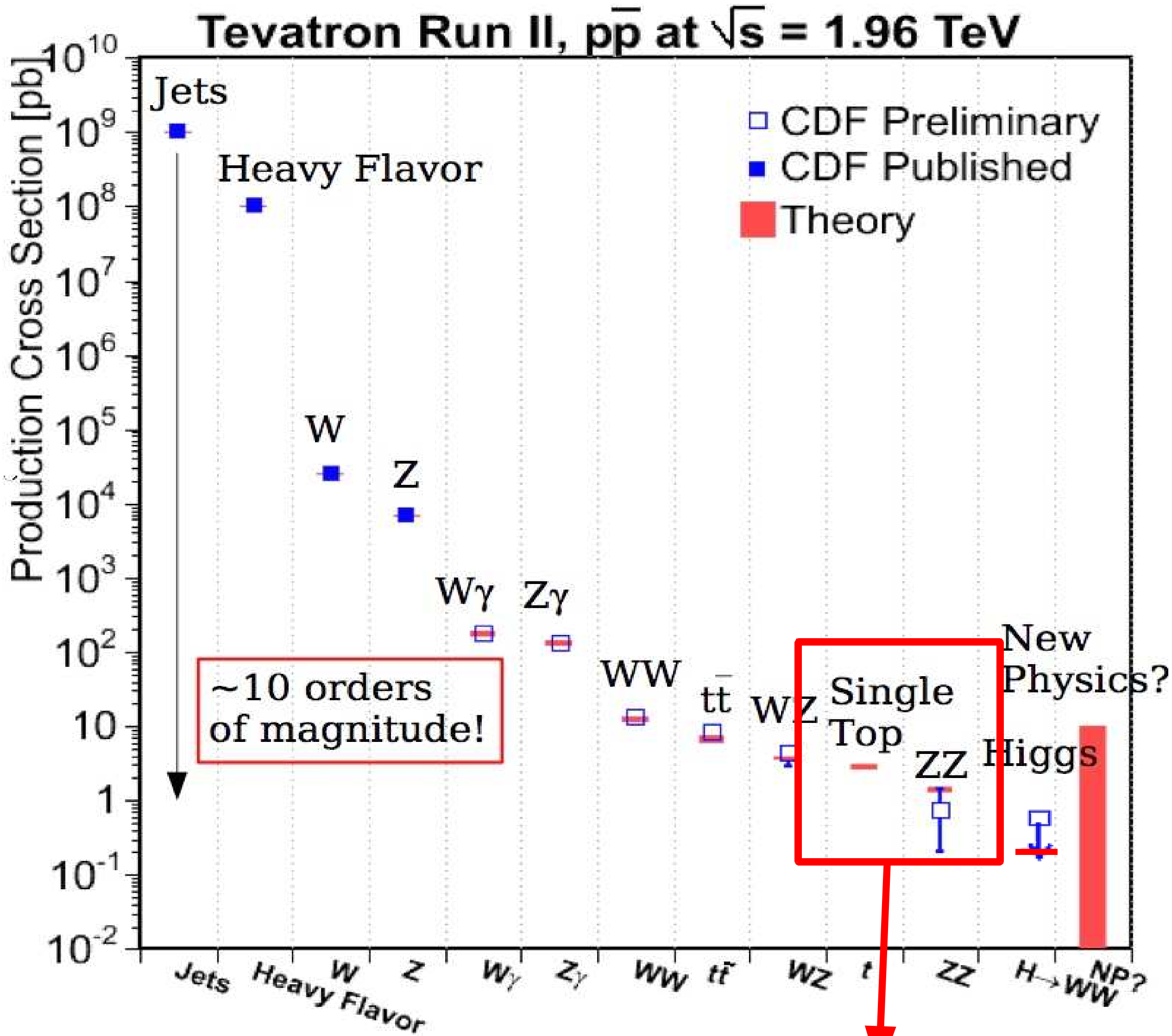
The Tevatron at Fermilab: DØ and CDF



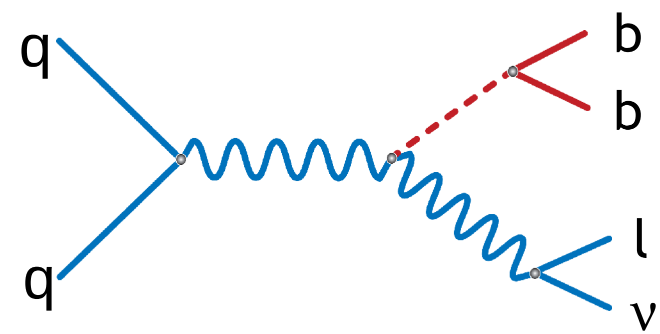
Two multipurpose detectors: D0 and CDF collecting data with high efficiency.

- excellent lepton ID
  - muon systems
  - EM cal and tracking.
- Good calorimeters for jet energy resolution)
- Silicon detectors for identifying b-jets

The Challenge



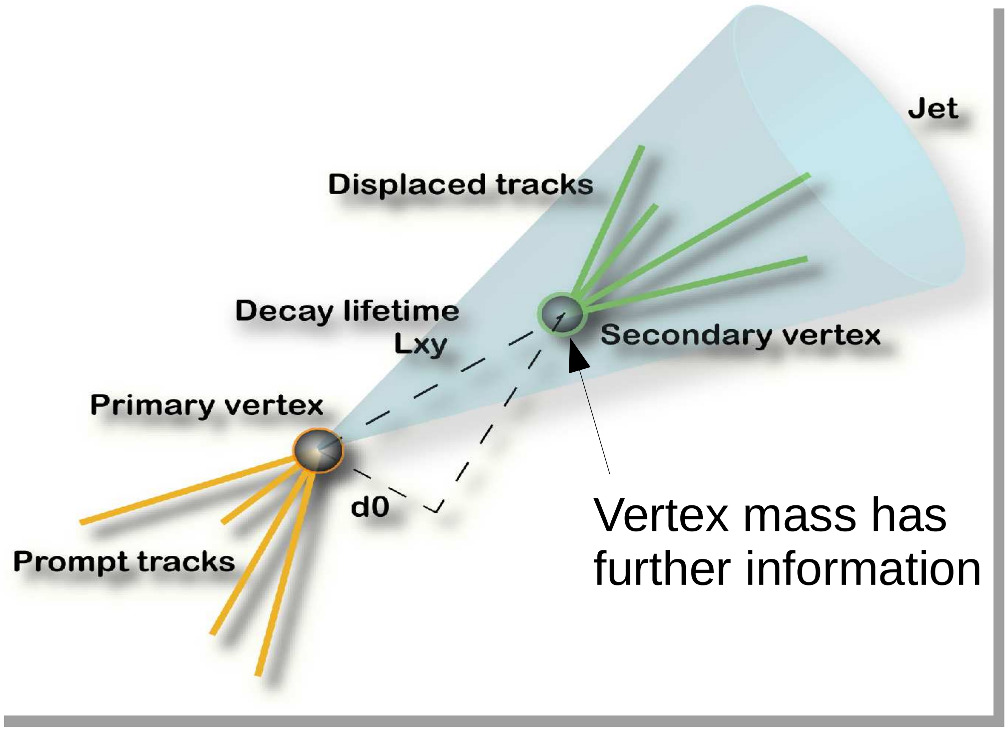
Higgs production very rare. Initial S/B < 10^{-10}



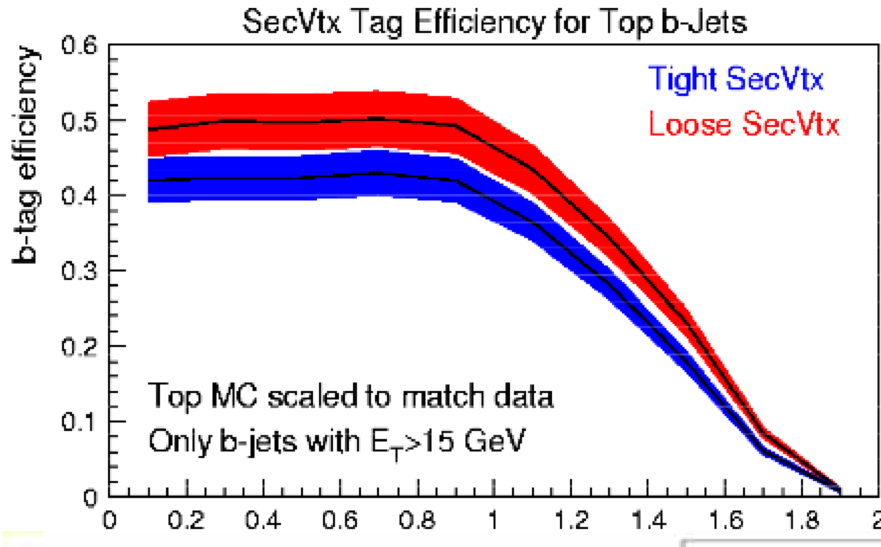
- First **Trigger** on:
  - high P_T leptons (also τ)
  - MET (+jets)
- Then, improve s/b by
  - efficient lepton ID
  - B-tagging
  - Advanced multivariate techniques

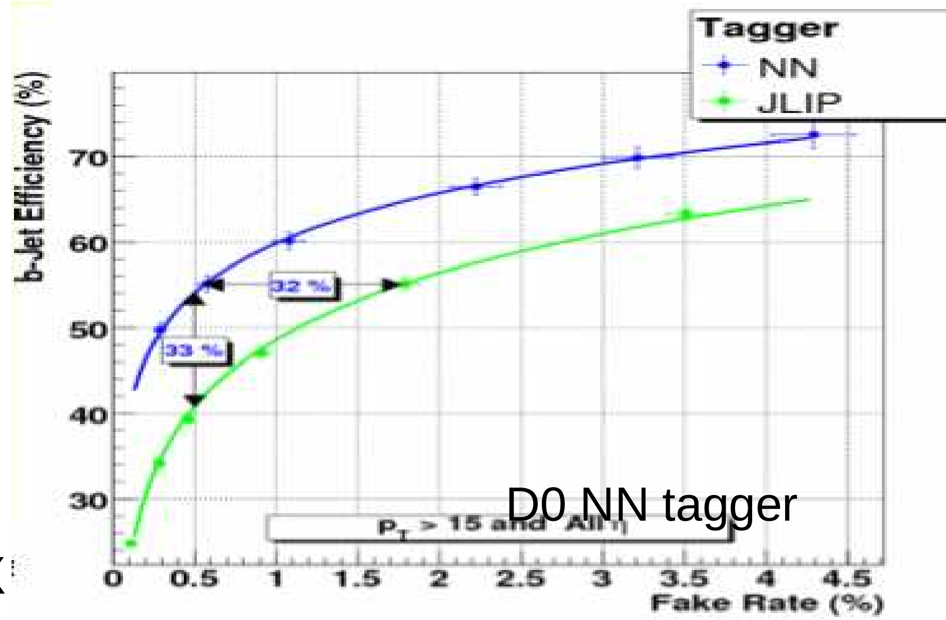
Recently started to see the rarest of these:
- testing ground for analysis techniques: (single) top, observation of ZZ
- all processes are crucial for background modeling eg: Wb, Wbb, Zbb

Important tool: B-jet identification



Vertex mass has further information





D0 NN tagger

B-tagging by finding secondary vertex

- DØ: powerful NN tagger
- CDF:
  - Secondary vertex tagger (SECVTX)
  - NN flavour separator to improve SECVTX output.
  - Jet probability tagger.

Beyond the Standard Model Higgs Searches

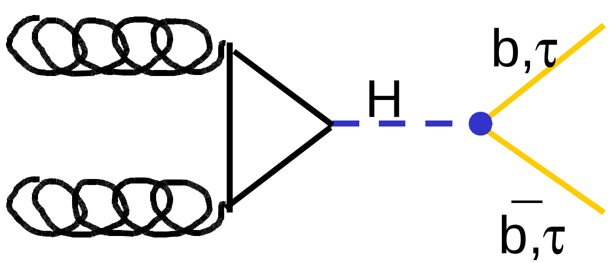
Beyond SM Higgs Scenarios

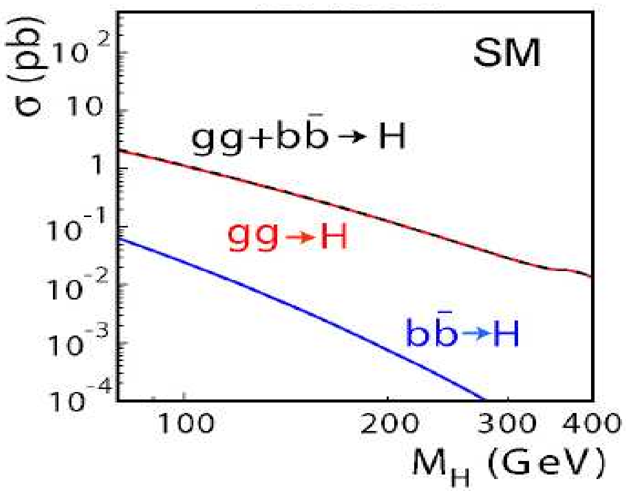
MSSM Higgs sector:
2 charged Higgses
- H^+ H^-

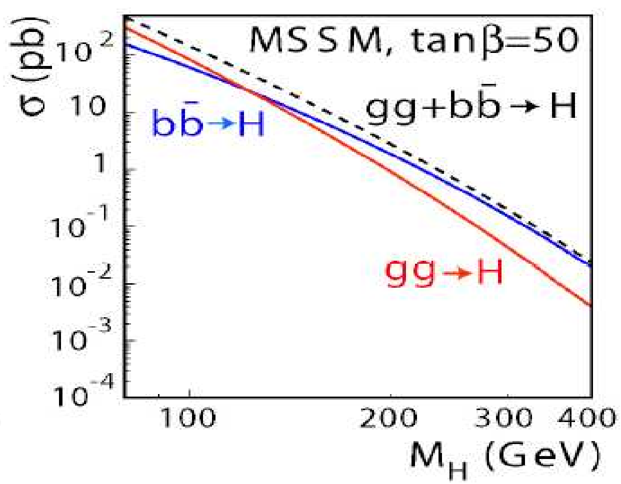
3 neutral ones:
- A: CP-odd
- h & H: cp even

- A has ~same mass as h or H and is SM-like.
- Coupling to down-type fermions enhanced for large tan β

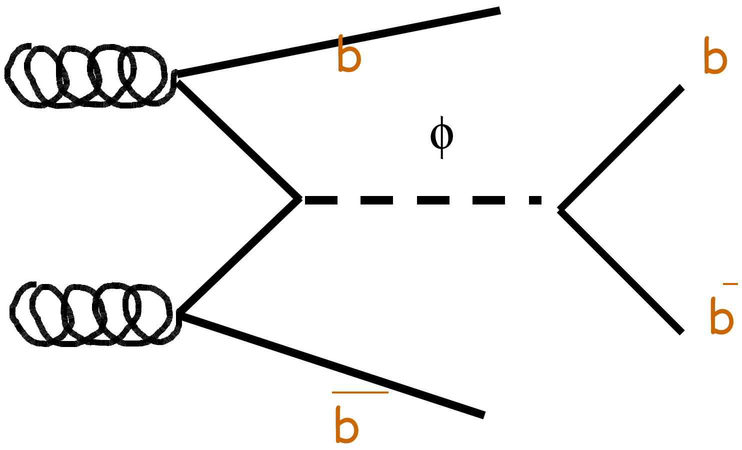
- CDF and D0 looked for H^+, H^- and H^{++}, H^{--}
  - direct production, e.g. decay into top
  - top decays into charged Higgs
- Several searches for SM-like Higgs in MSSM:
  - Sensitive to direct production in models with large tan β.
  - will discuss: bbH→ bbbb and H→ττ
- Fermiophobic Higgs, decaying into WW or γγ
  will discuss: H→γγ (DØ), WH→ WWW

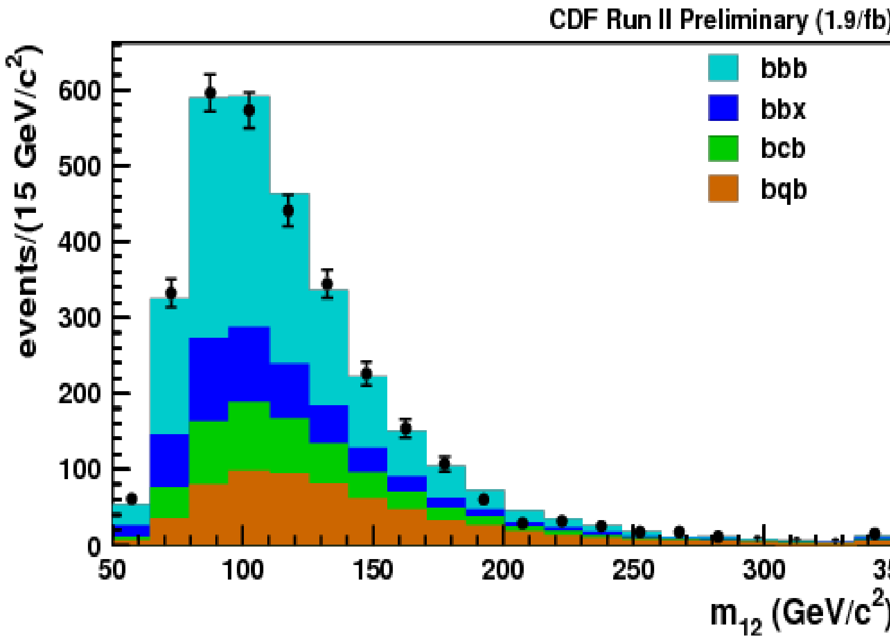




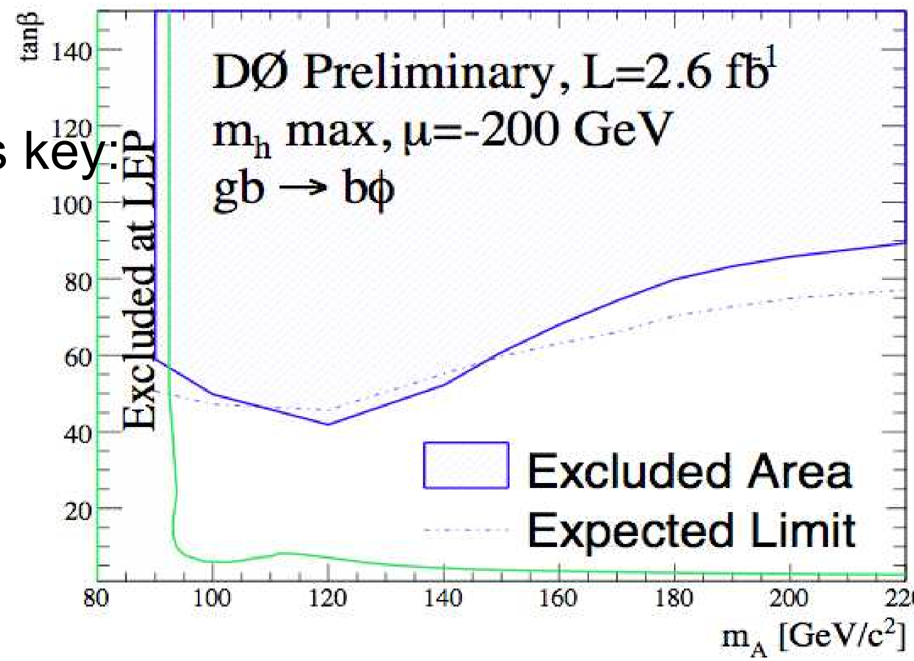


bϕ -> bbb searches



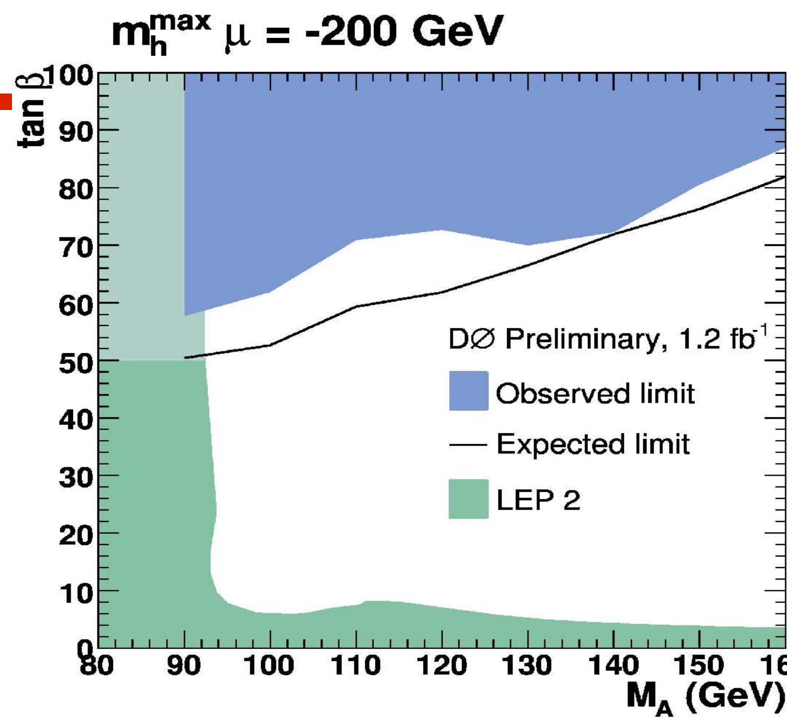


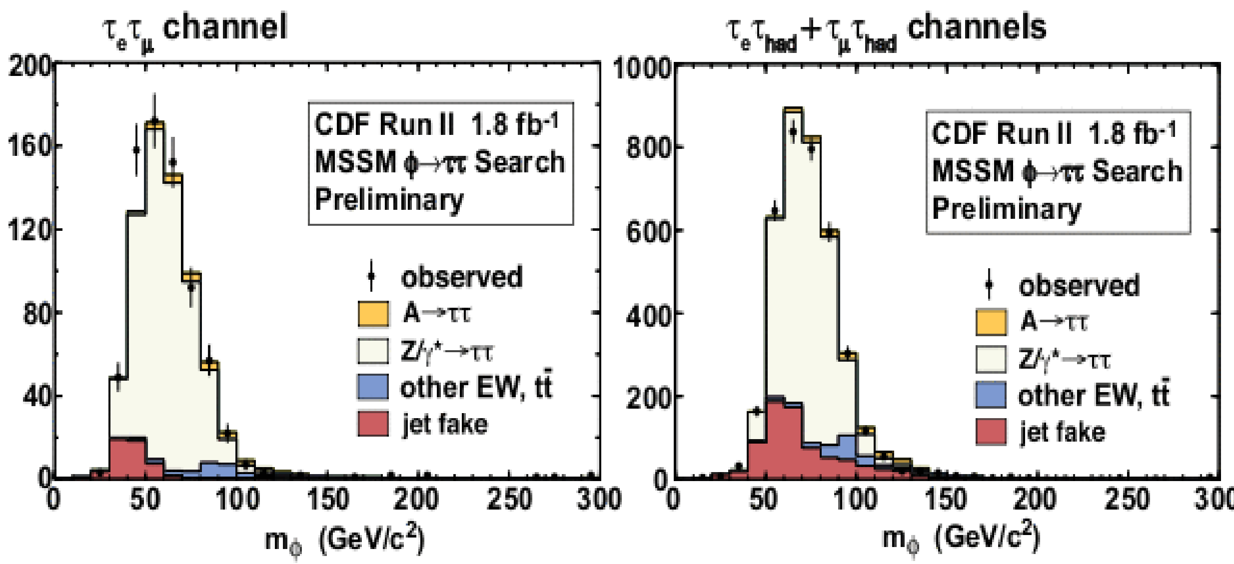
- High E_T jets from f decay: search for mass peak in 2 leading jets.
- require 3 b-jets for optimal S/B
- Understanding composition of b-tagged jets is key:
  - CDF: Vertex mass fits
  - DØ: multiple operating points of NN tagger
- DØ also has a bϕ → bττ search with similar sensitivity.

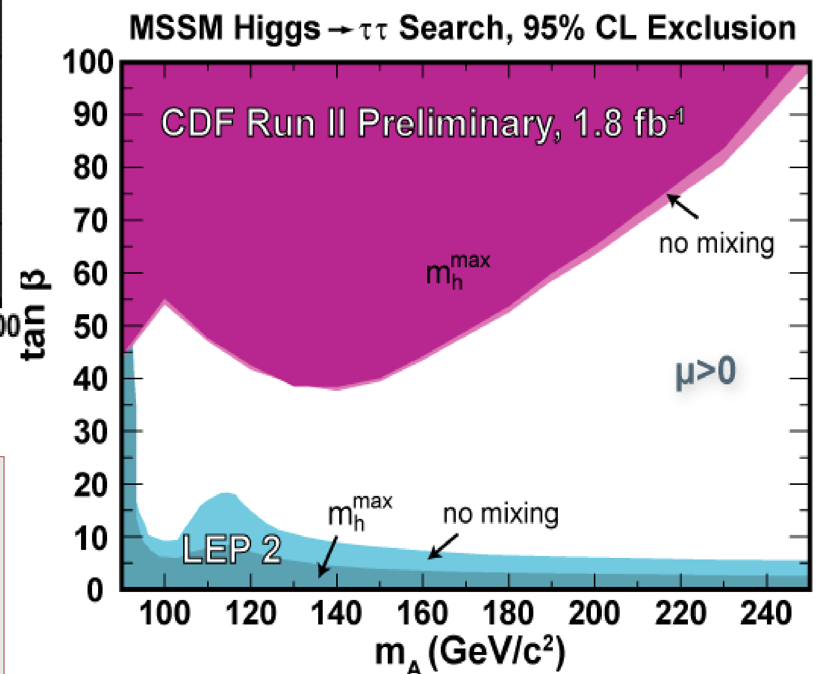


$\phi \rightarrow \tau\tau$ searches

- $\tau\tau$ signature pure enough to search for direct production
- Hadronic τ id capabilities developed and tested on large samples of W and Z events.





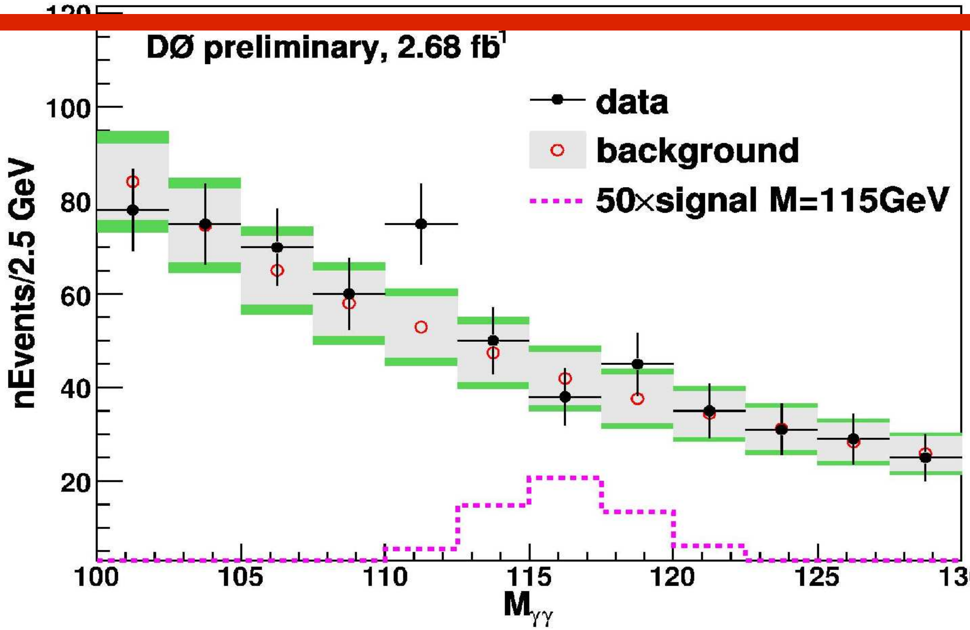


Similar limits across experiments and channels ($\tau\tau$ and bbb) $\rightarrow$ Combining results will greatly improve the limits.

Fermiophobic Higgs:

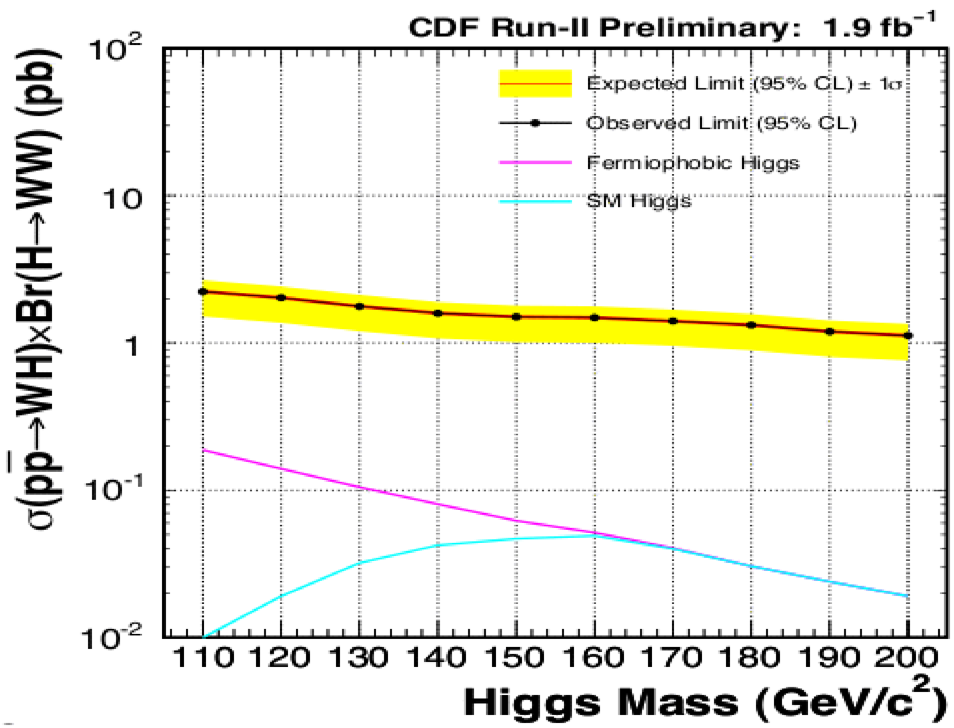
DØ: H → γγ

- Photons selected with NN using calorimeter and track information.
- Look for mass peak
- Really a standard model search, with increased sensitivity if Higgs is fermiophobic
  - Branching ratio up to 10% in stead of SM value of 1e-3.



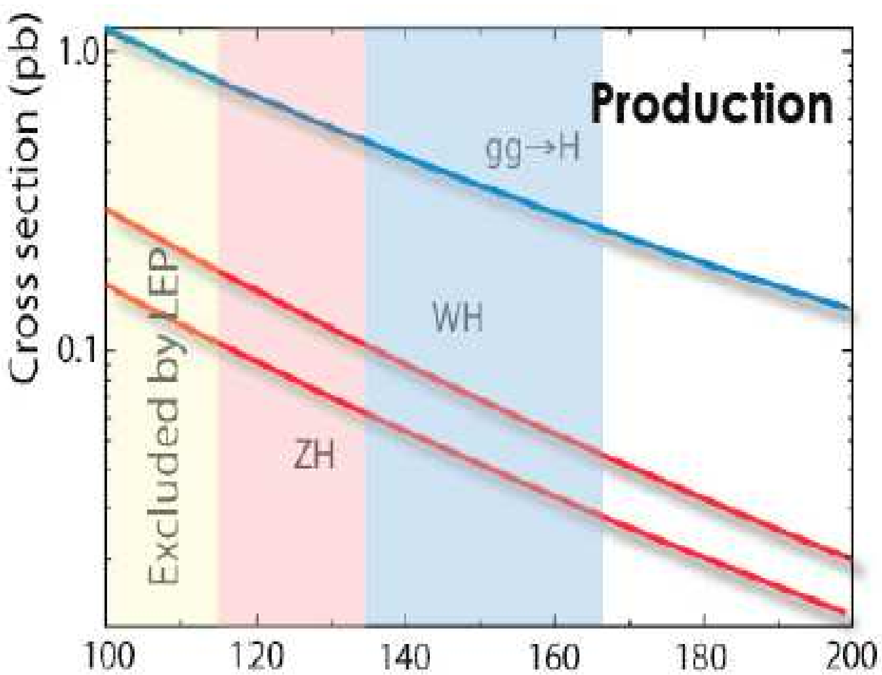
WH → WWW

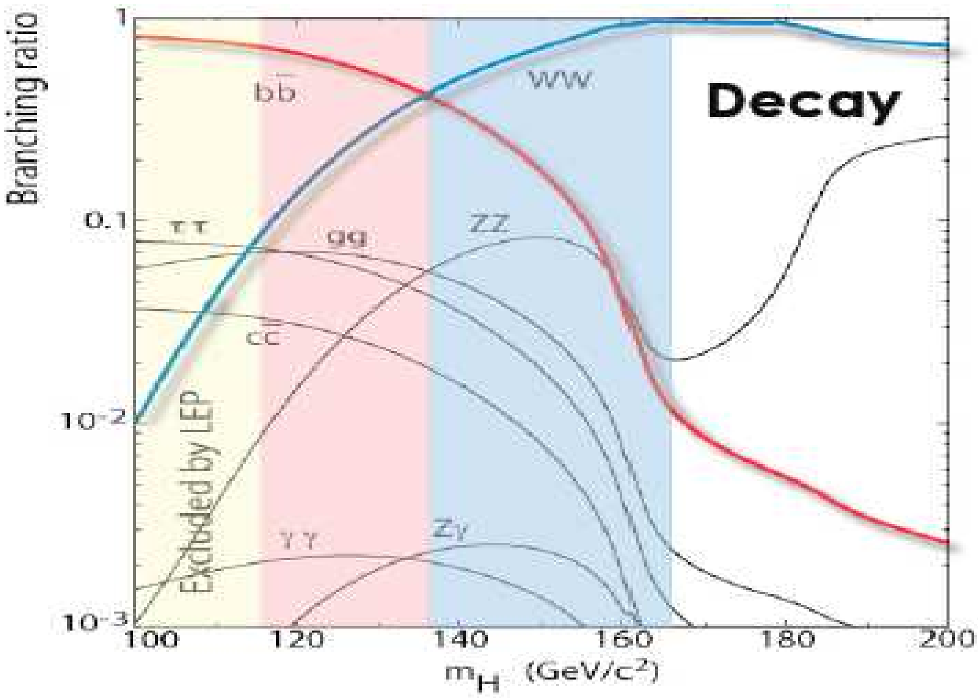
- Look for two same-sign leptons
- Also sensitive to SM, at high mass where H → WW
- At low mass: more sensitive if H is fermiophobic.
- DØ has competitive result.



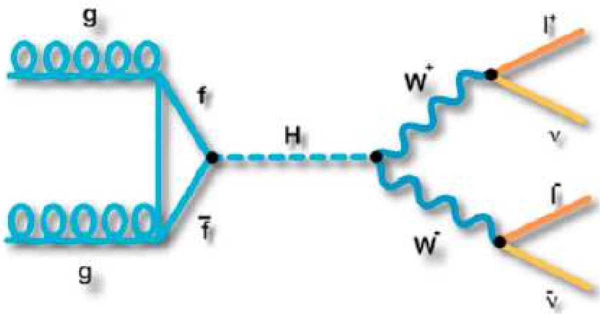
Standard Model Higgs Searches

SM Production and decay modes



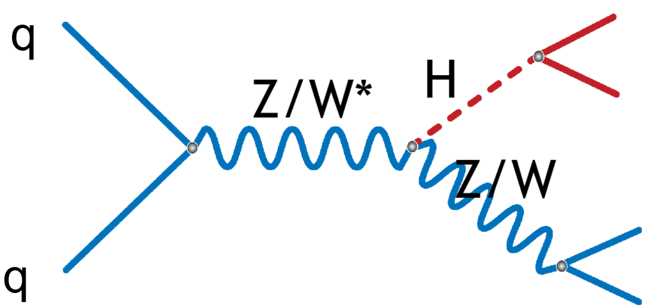


High Mass
(M_H> ~135 GeV)



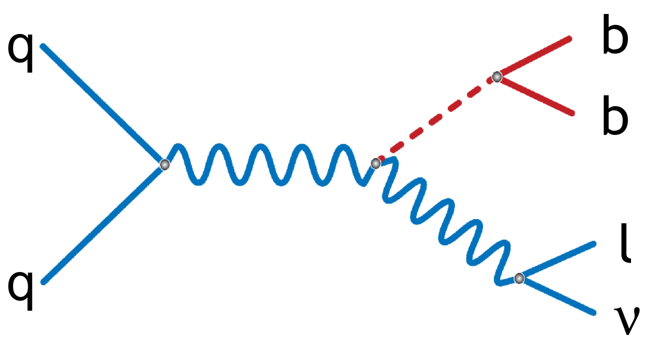
- H →WW → ll νν.
- backgrounds low enough to use gg → H
- signature: leptons and MET

Low Mass
(M_H<~135 GeV)



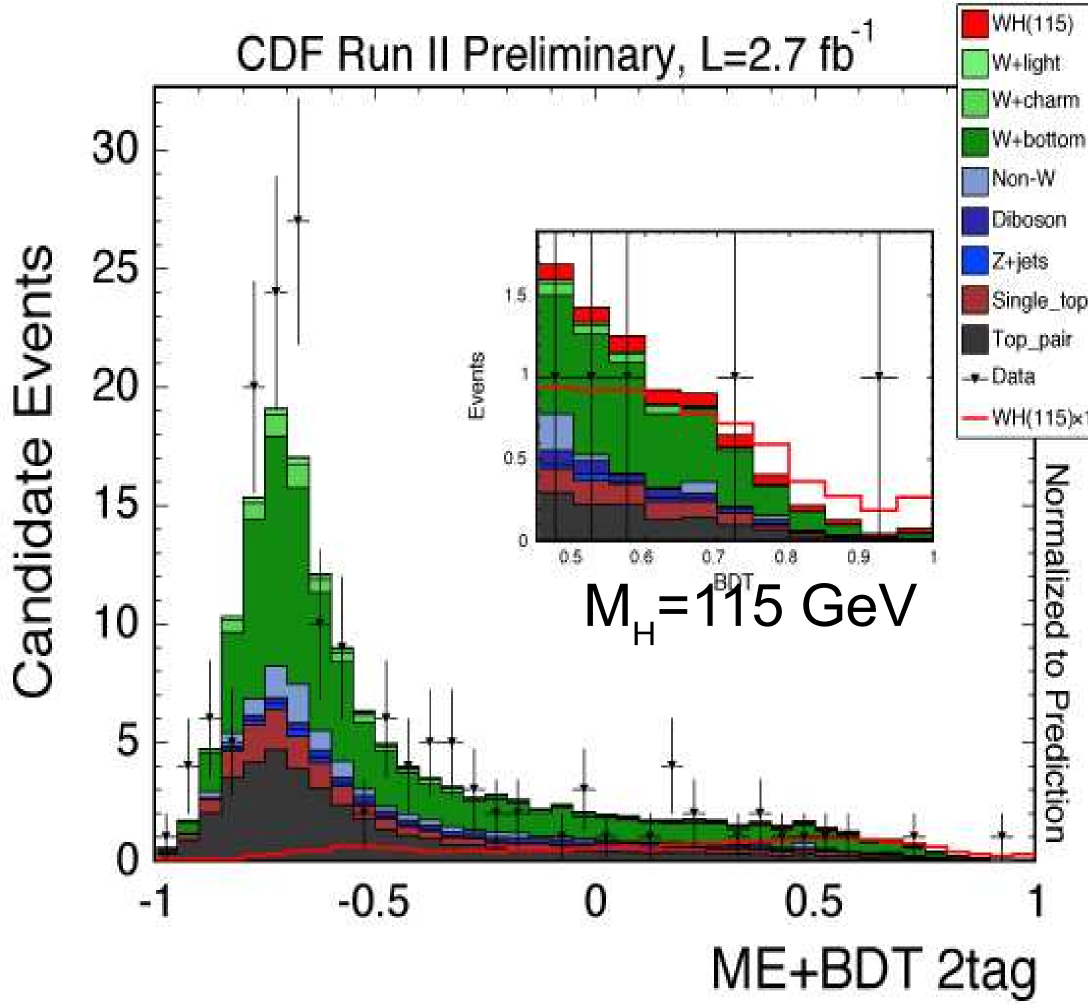
- Higgs goes to b's to τ's
- Identification of b-jets (or τ's)
- gg → H → bb swamped by background
- detect associated W or Z: leptons, MET

Low mass: WH → lνbb



- Signature: High E_T lepton, MET, bjets
- Use isolated tracks as leptons and use forward electrons
- 2 bjets: require one or two tags, treated separately
- DØ: allow events with 3 jets.
- CDF: ME + BDT includes: NN b-tagger, and NN for jet corrections.

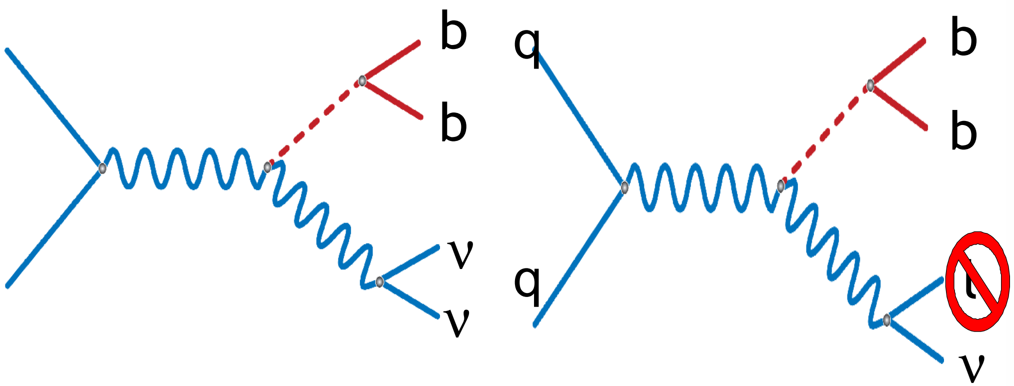
- Major background: Wbb, W+mistags, (modeled by a combination of data and MC)

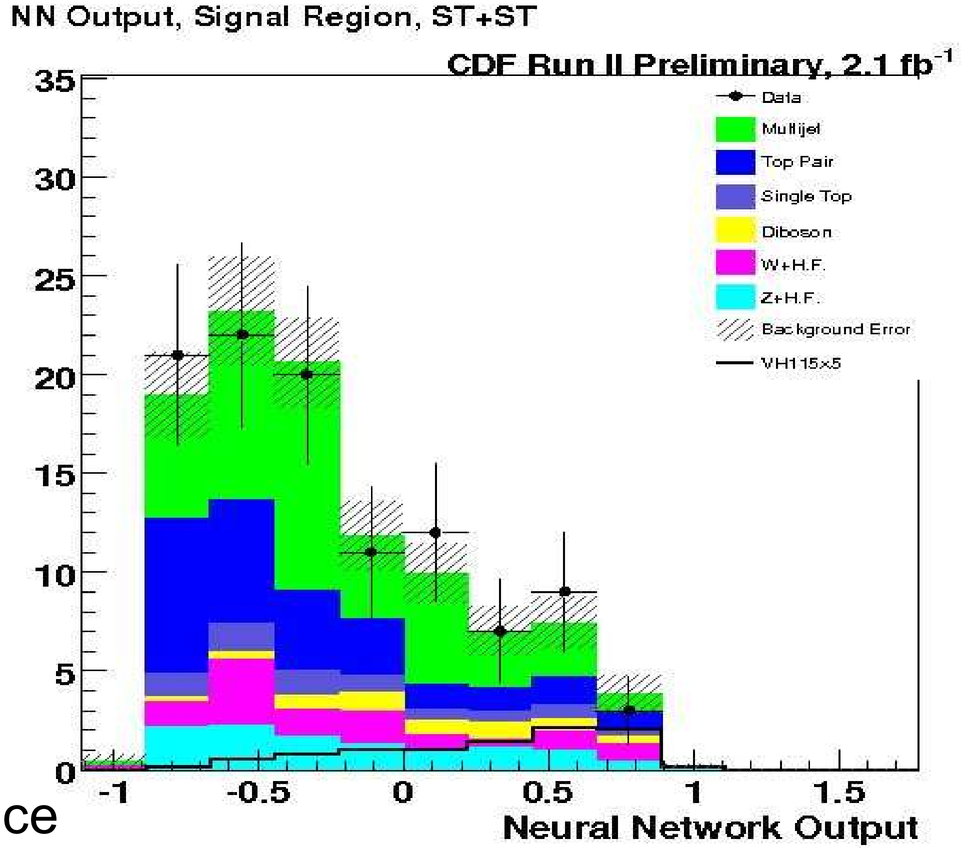


Results at mH = 115GeV: 95%CL Limits/SM

Analysis	Lum (fb^{-1})	Higgs Events	Exp. Limit	Obs. Limit
CDF NN	2.7	8.3	5.8	5.0
CDF ME+BDT	2.7	7.8	5.6	5.7
DØ NN	1.7	7.5	8.5	9.3

Low mass: Missing E_T + b-jets





- Signature: Large MET and b-jets.
- Also sensitive to WH, where the lepton is undetected.
- challenge: QCD events modeled from data

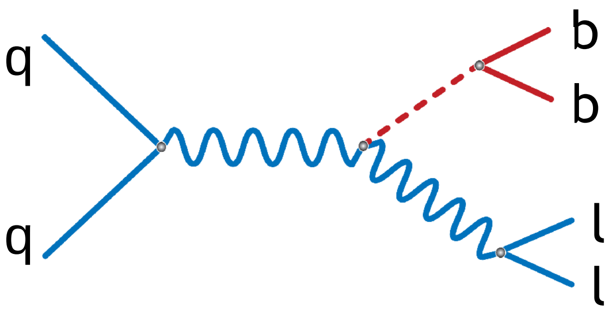
- CDF NN analysis
  - allows 3-jet events, giving extra acceptance to W->W$\rightarrow\tau\nu$. (D0 has dedicated W$\rightarrow\tau\nu$ search)
  - 1 or 2 b-tags (or 2 mixed b-tags)
  - Use H1 algorithm for E_{jet} measurement

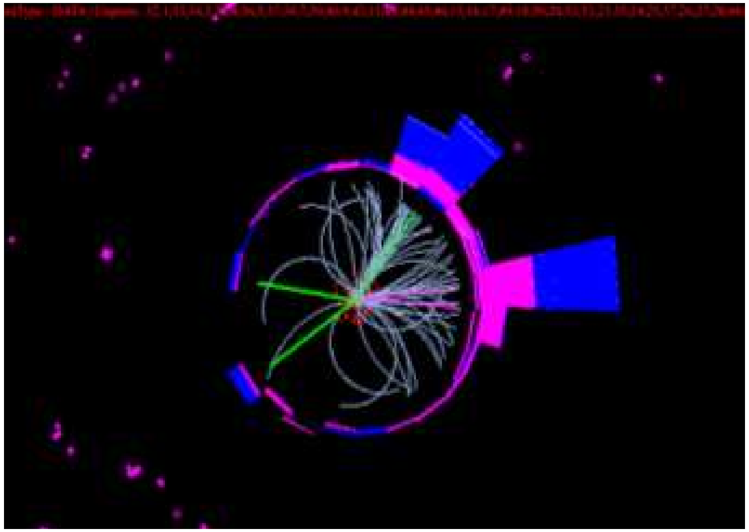
- DØ BDT analysis
  - Use NN b-tagger asymmetrically (one tight, one loose tag).
  - 24 input variables.

Results at mH = 115GeV: 95%CL Limits/SM

Analysis	Lum (fb^{-1})	Higgs Events	Exp. Limit	Obs. Limit
CDF NN	2.1	7.3	6.3	7.9
DØ BDT	2.1	3.7	8.4	7.5

Low mass: l^+l^- + b-jets

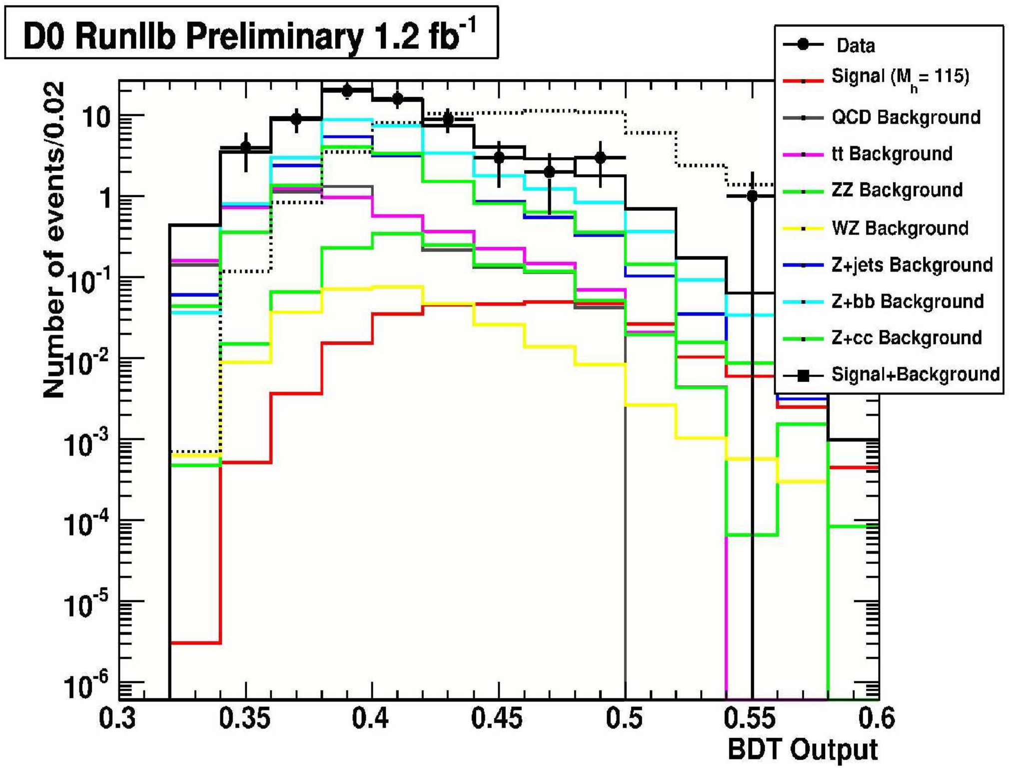




Very clean (M_{ll}=M_z), but very rare → maximize acceptance:

- loose b-tagging (1 or 2 tags)
- extra leptons: isolated tracks, Calorimeter-only electrons. (CDF)

• CDF uses MET to constrain jet energies.

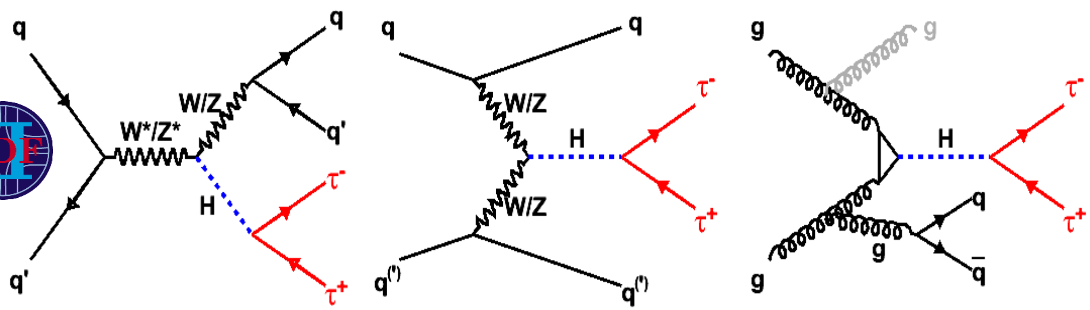


Results at mH = 115GeV: 95%CL Limits/SM

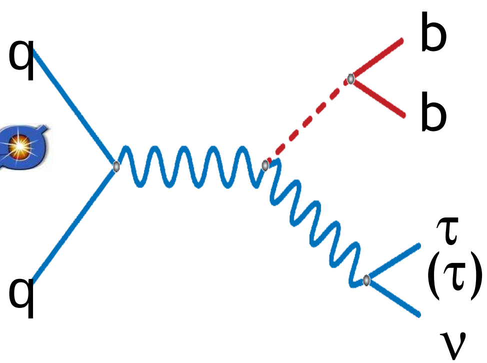
Analysis	Lum (fb^{-1})	Higgs Events	Exp. Limit	Obs. Limit
CDF NN	2.4	1.8	11.8	11.6
CDF ME(120)	2.0	1.4	15.2	11.8
DØ NN,BDT	2.3	2.0	12.3	11.0

Low mass: additional channels:

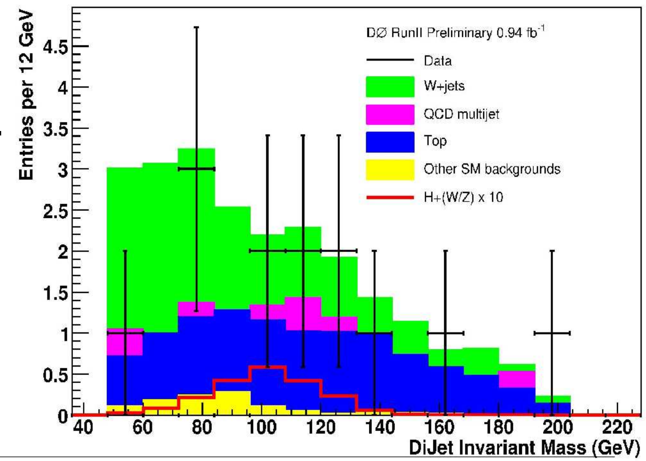
not as sensitive, but help in the combination.

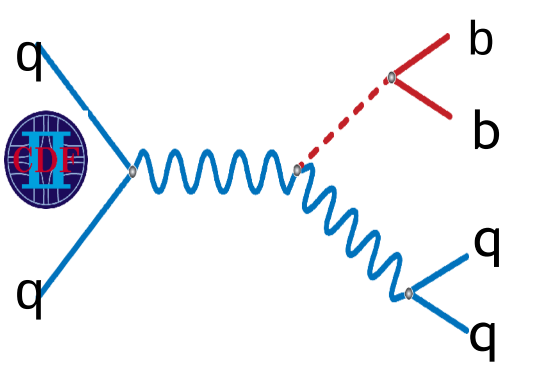


- $\tau_{had} + \tau_{lep}$ + 2 jets
- Uses multiple NN's to reject Z, ttbar, QCD.
- 2.2 fb^{-1}
- obs(exp)/sm: 30.5 (24.8) @M_H=115 GeV

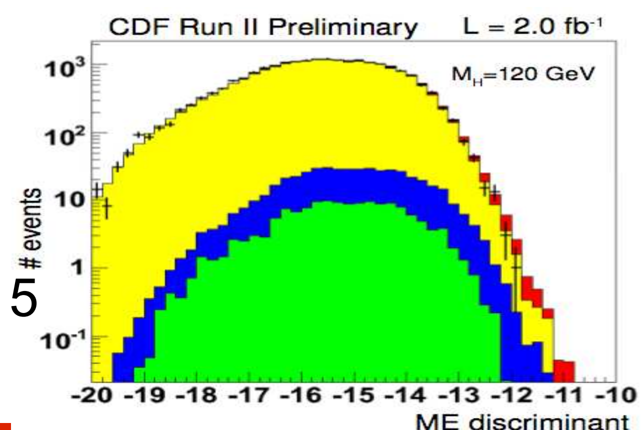


- Hadronic τ + MET + 2 b jets
- Use DiJet mass to extract signal
- 0.9 fb^{-1}
- obs(exp)/sm: 35.4 (42.1) @M_H=115 GeV





- 4 jets, at least 2 b jets
- Large BR for W/Z→qq
- Large QCD bkg, model from data
- ME technique
- obs(exp)/sm: 37.0 (36.6) @M_H=115



Summary of low mass SM Higgs searches

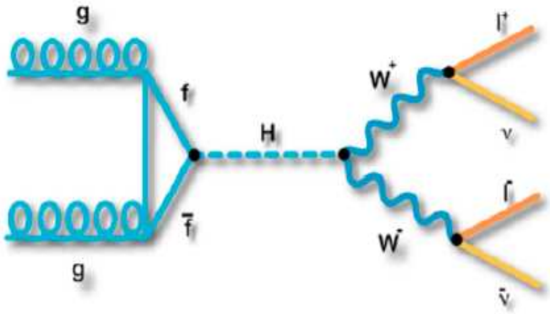
$m_H = 115$ GeV/c^2

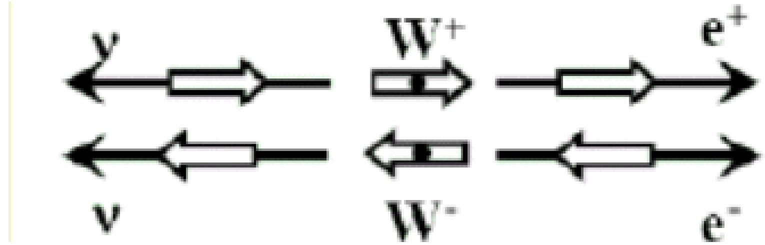
Channel	CDF 95% C.L. Limits $\sigma \cdot BR/SM$ obs (exp)	DØ 95% C.L. Limits $\sigma \cdot BR/SM$ obs (exp)
$WH \to l\nu bb$	5.7 (5.6)* 2.7fb^{-1}	9.3 (8.5) 1.7fb^{-1}
$WH \to \tau\nu bb$	-	35.4 (42.1) 0.9fb^{-1}
$VH \to qqbb$	37.0 (36.6) 2.0fb^{-1}	-
$ZH \to llbb$	11.6 (11.8) 2.4fb^{-1}	11.0 (12.3) 2.3fb^{-1}
$VH \to \nu\nu/(l)bb$	7.9 (6.3)* 2.1fb^{-1}	7.5 (8.4) 2.1fb^{-1}
$ttH \to l\nu bbbbqq$	-	63.9 (45.3) 2.1fb^{-1}
$H \to \gamma\gamma$	-	30.8 (23.2) 2.7fb^{-1}
$H \to \tau\tau$	30.5 (24.8) 2.2fb^{-1}	-

* in case of multiple analyses, showing result with best expected limit

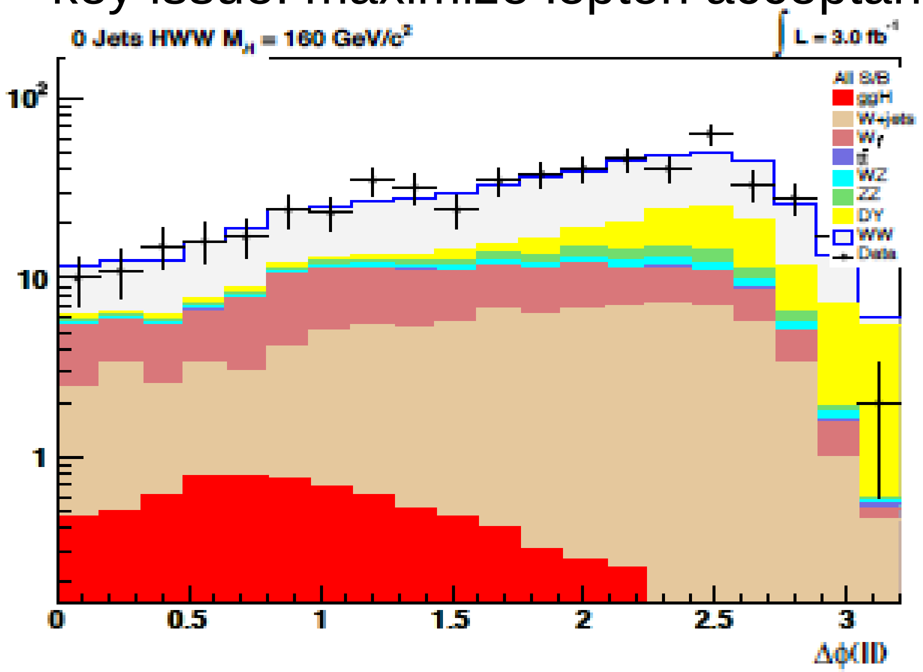
on to high mass....

High Mass Standard Model Higgs Searches.





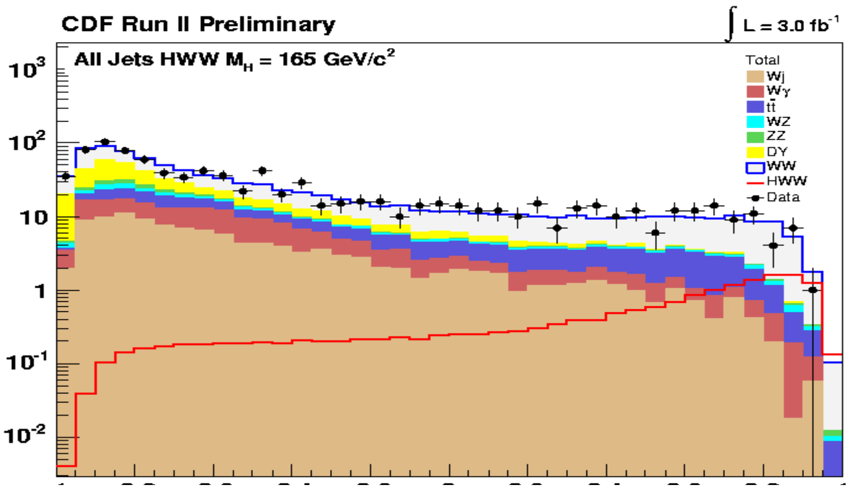
Signature
- Two leptons in ~same direction due to spin correlation
- 1 or 2 additional jets (associated production, VBF)
- key issue: maximize lepton acceptance.

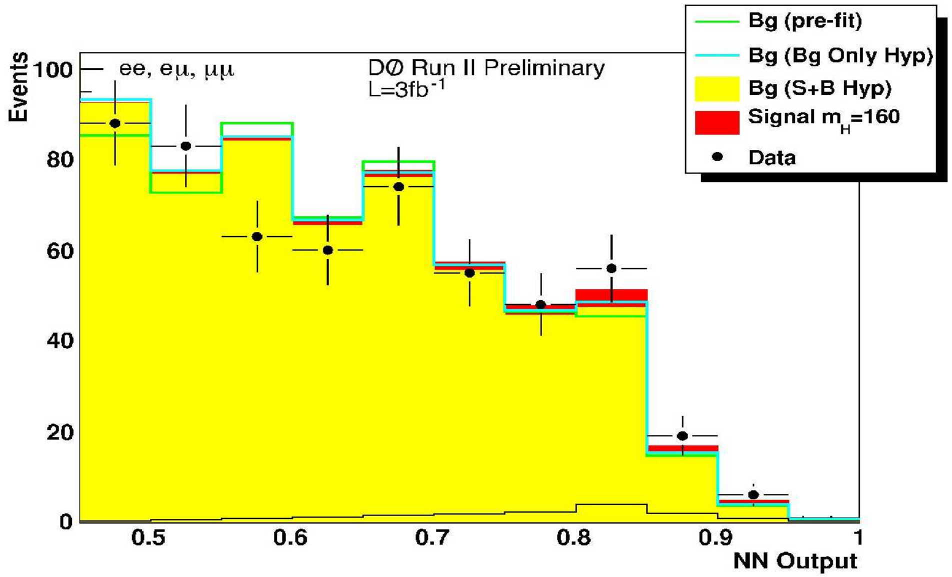


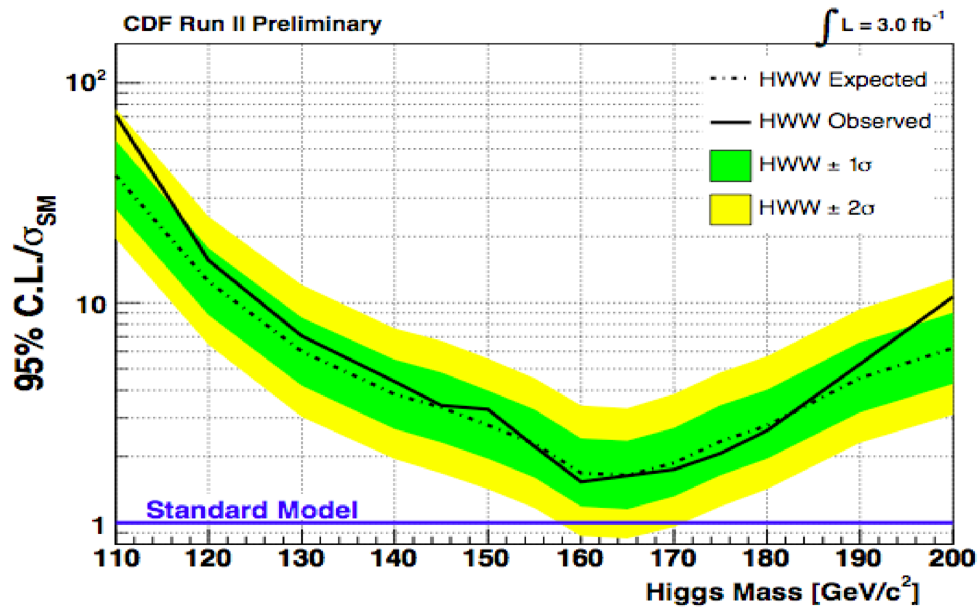
CDF:
- analyze in 0,1 and >1 jet events bins
- 0 jets: NN with ME likelihood as one of the inputs.
- Separate high S/B and low S/B leptons.
- 1,2 extra jets: NN analysis. Adds signal from Associated production and VBF.

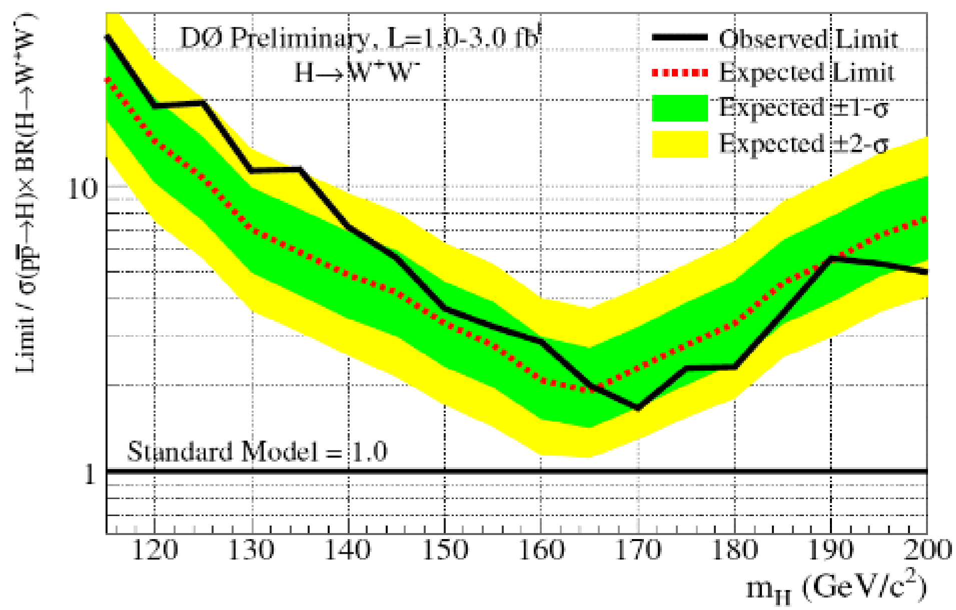
D0: NN analysis.
- allow for jets to be present.
- 14 variables,
- separate ee, eμ, μμ channels

High Mass Standard Model Higgs Searches.









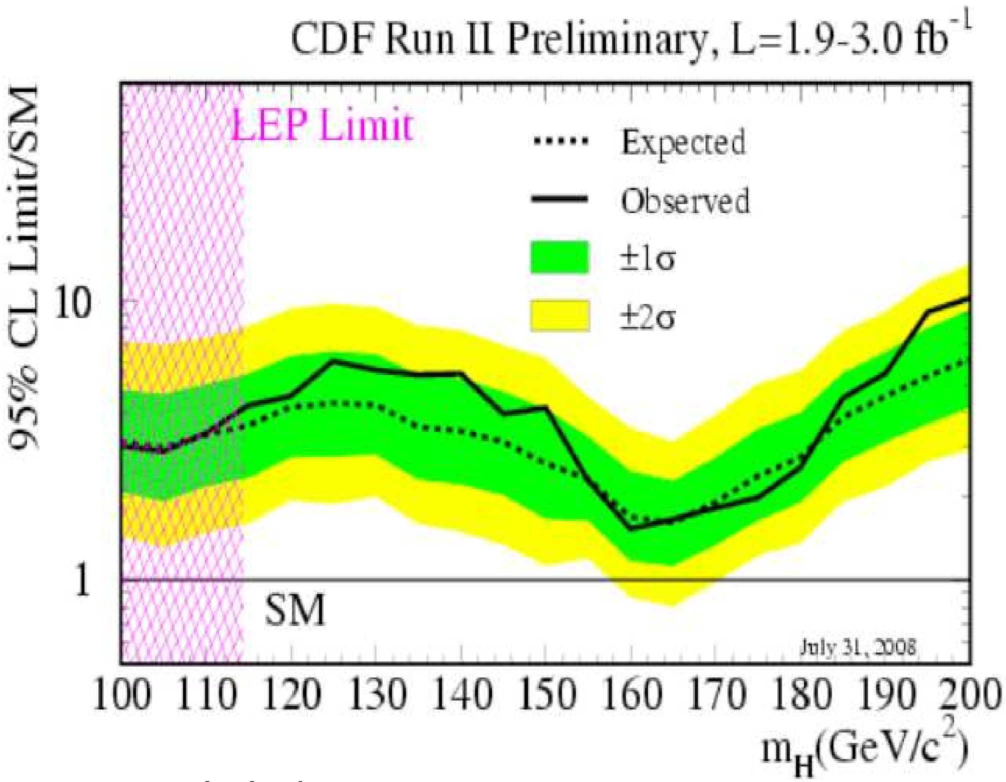
Results at m_H = 165GeV : 95%CL Limits/SM

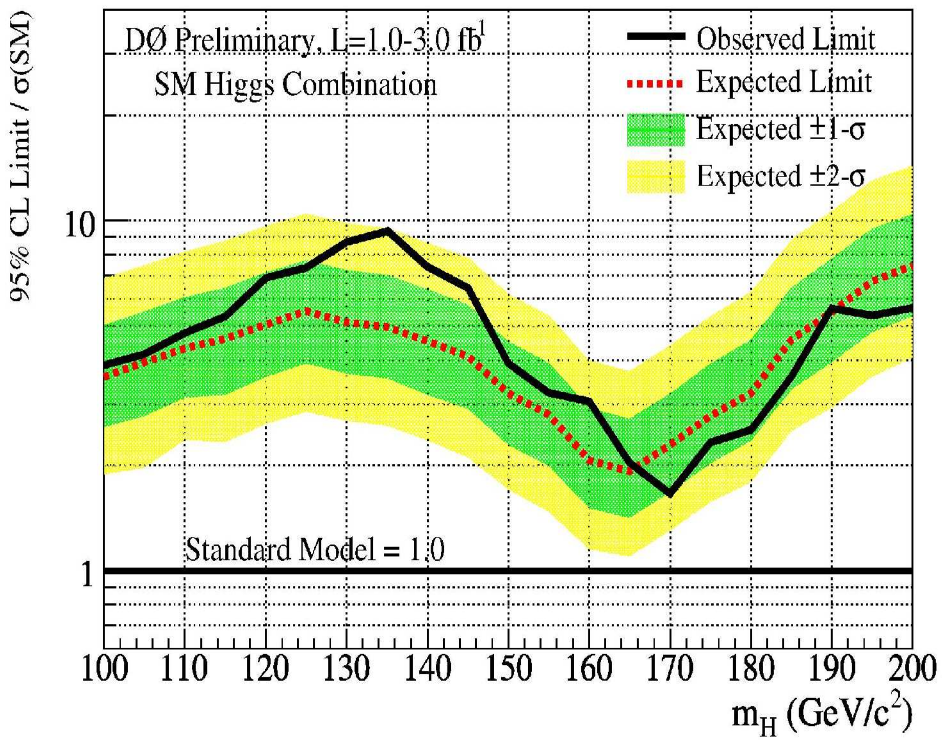
Analysis	Lum (fb^{-1})	Higgs Events	Exp. Limit	Obs. Limit
CDF ME+NN	3.0	17.2	1.6	1.6
DØ NN	3.0	15.6	1.9	2.0

NB: Also contributes at lower MH!

Combined SM Higgs results

Combined full mass range results, per experiment



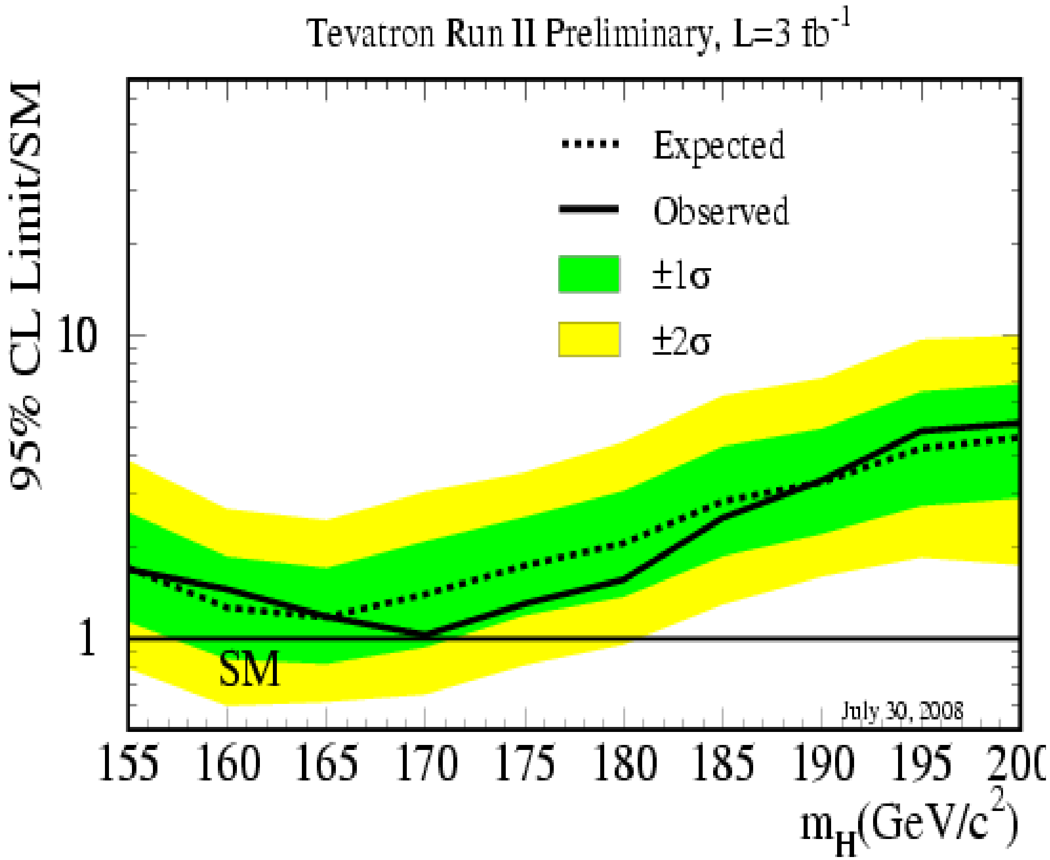


95%CL Limits/SM

Analysis	M_H = 115 GeV		M_H = 165 GeV	
	exp	obs	exp	obs
CDF NN	3.6	4.2	1.6	1.6
DØ BDT	4.6	5.3	1.9	2.0

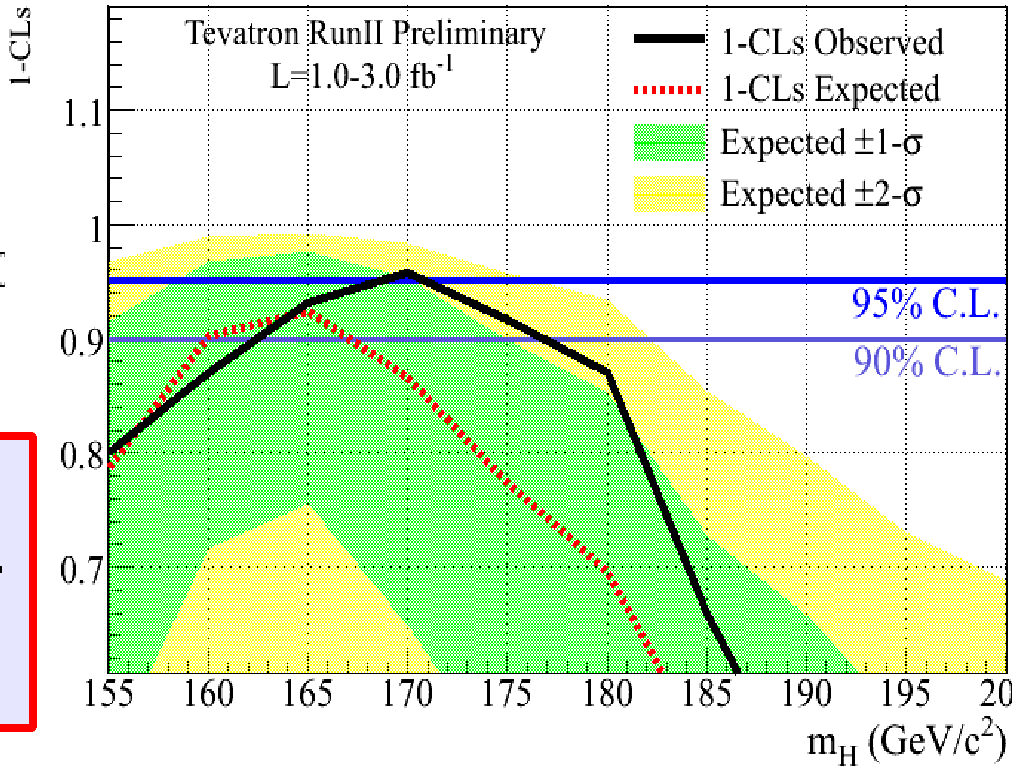
Tevatron-wide low-mass (>70 channels) difficult.
Full range combination coming soon.
Expect ~3 x σ(sm) at 115 GeV

Tevatron combined results: High mass SM Higgs



- Bayesian and Modified frequentist approaches used. (agree well).
- Systematics and their correlations between channels and experiments taken into account.

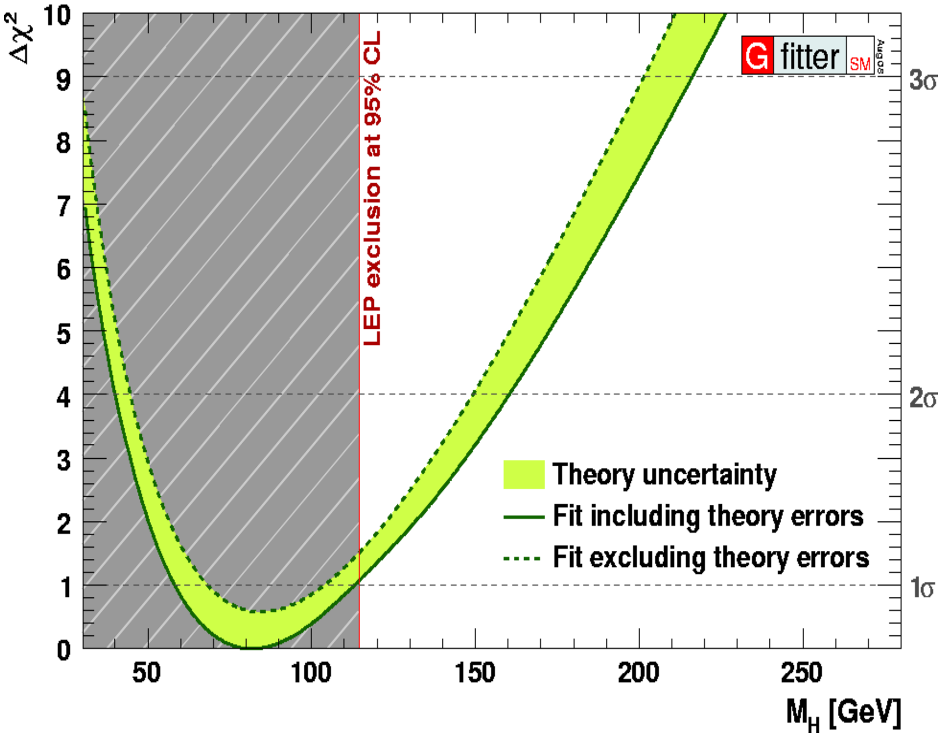
We exclude, at 95% CLs, M_H=170 GeV.
First direct exclusion since LEP!

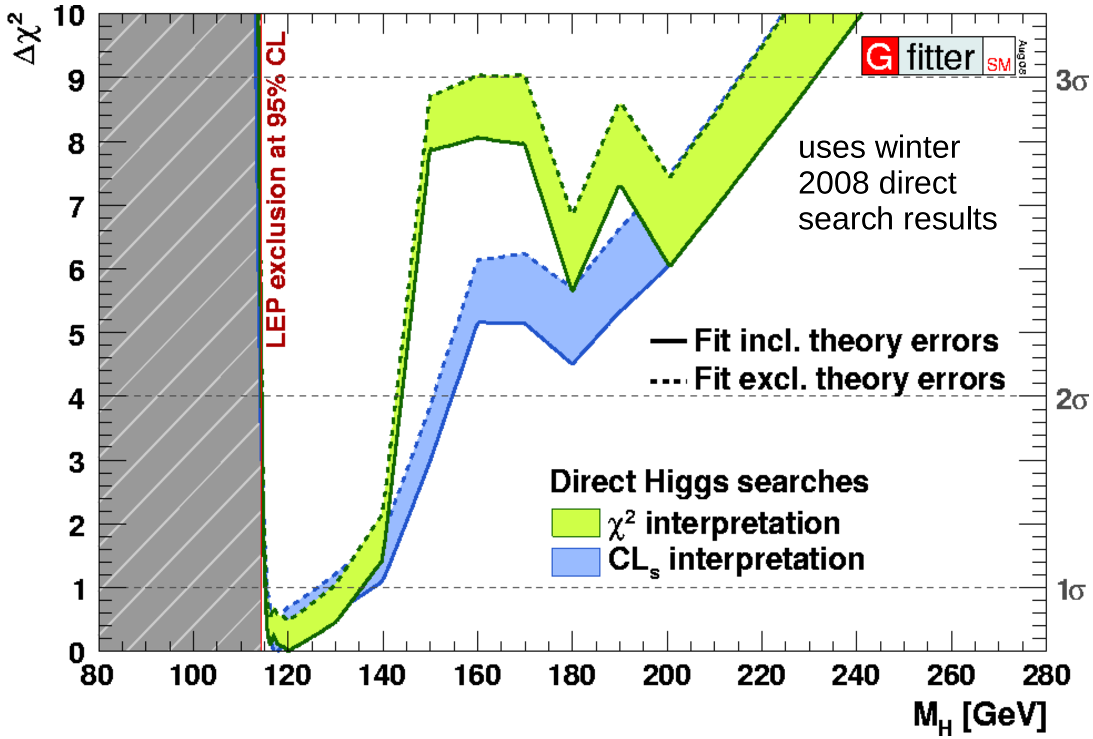


Conclusions:

- Both SM and Susy Higgs searches are being fiercely pursued
  - Tevatron performing well: Luminosity still increasing fast
  - Many improvements in the analysis techniques too.

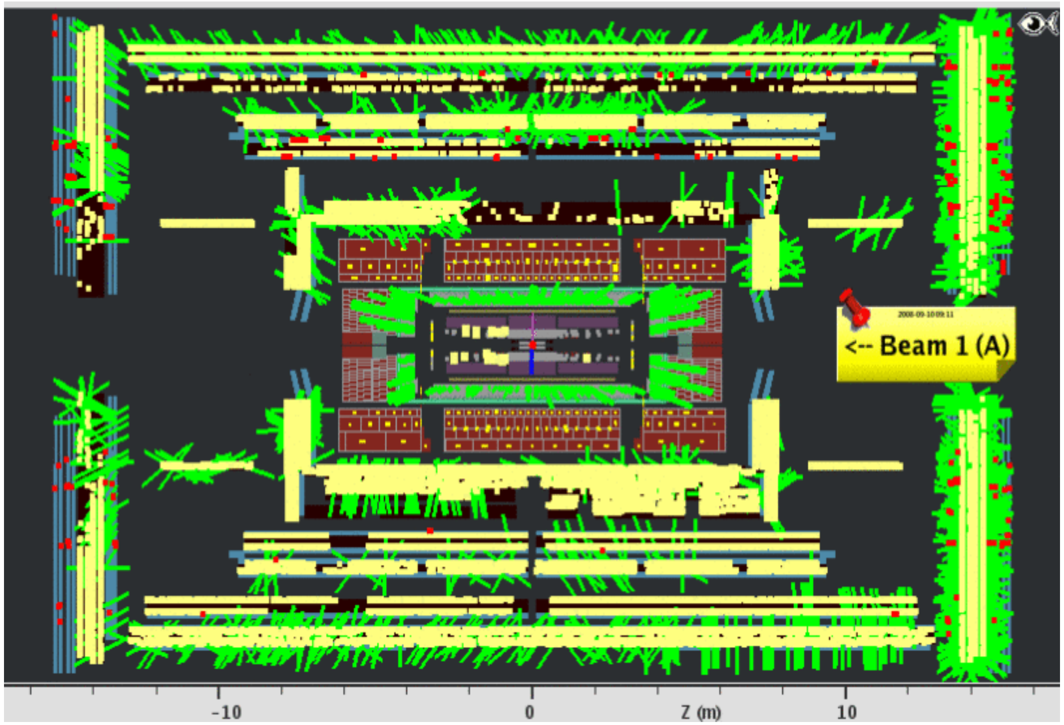
- MH=170 GeV Mass point now excluded and 95% Cls!
- Larger exclusion zone around 170 GeV will follow soon... or see first hints of excess.
- Many results still to come soon – e.g. combined Tevatron result for low masses. (expect factor of 3 above SM).



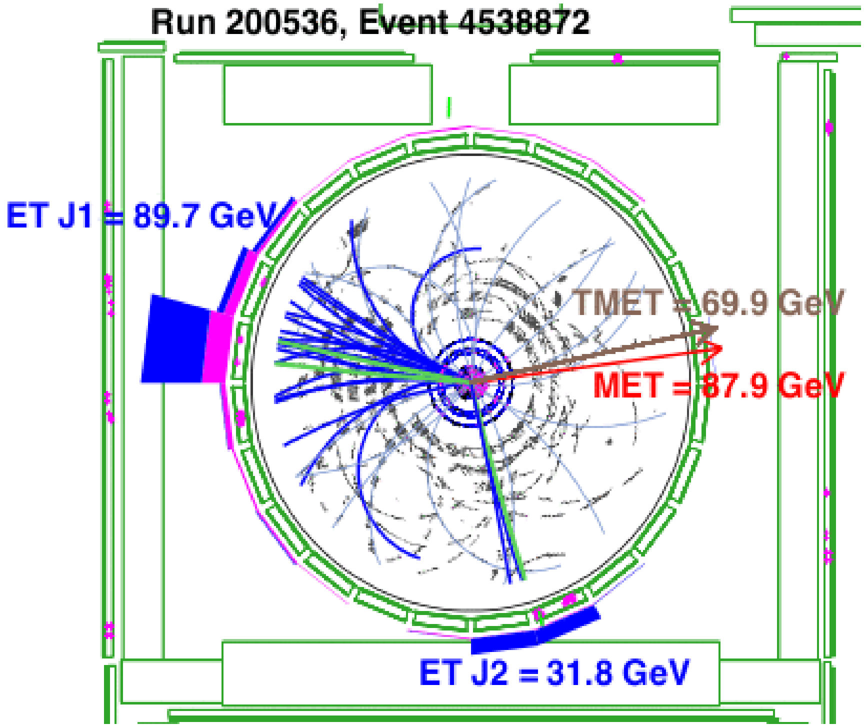


all results available from http://www-d0.fnal.gov/Run2Physics/WWW/results/higgs.htm
and http://www-cdf.fnal.gov/physics/new/hdg/hdg.html

“Motivation”



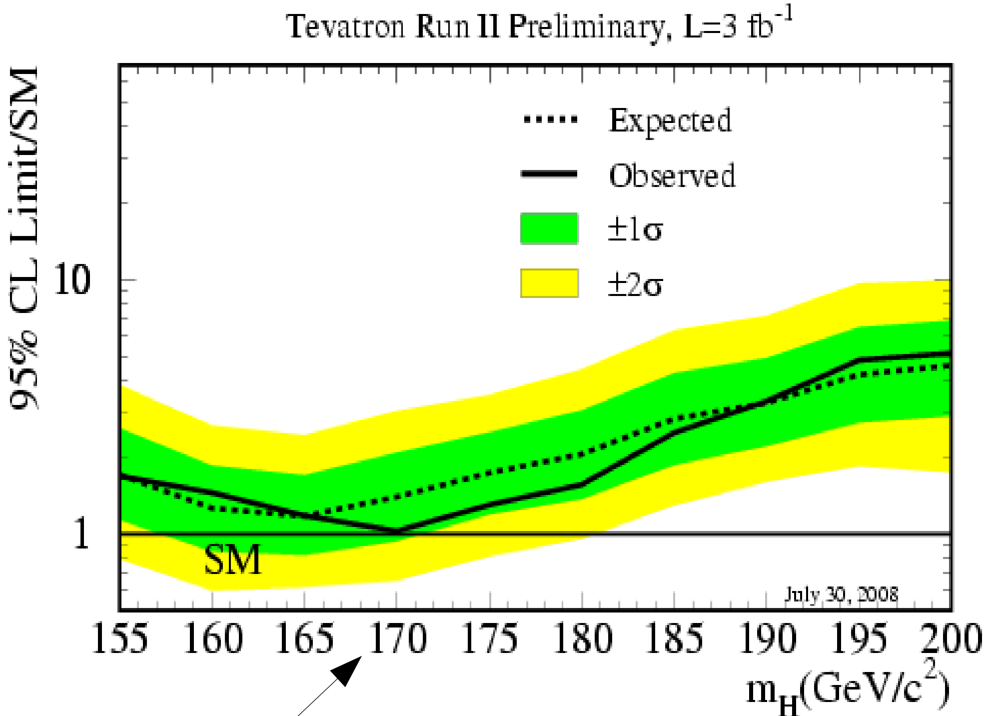
Atlas Sep 10 2008

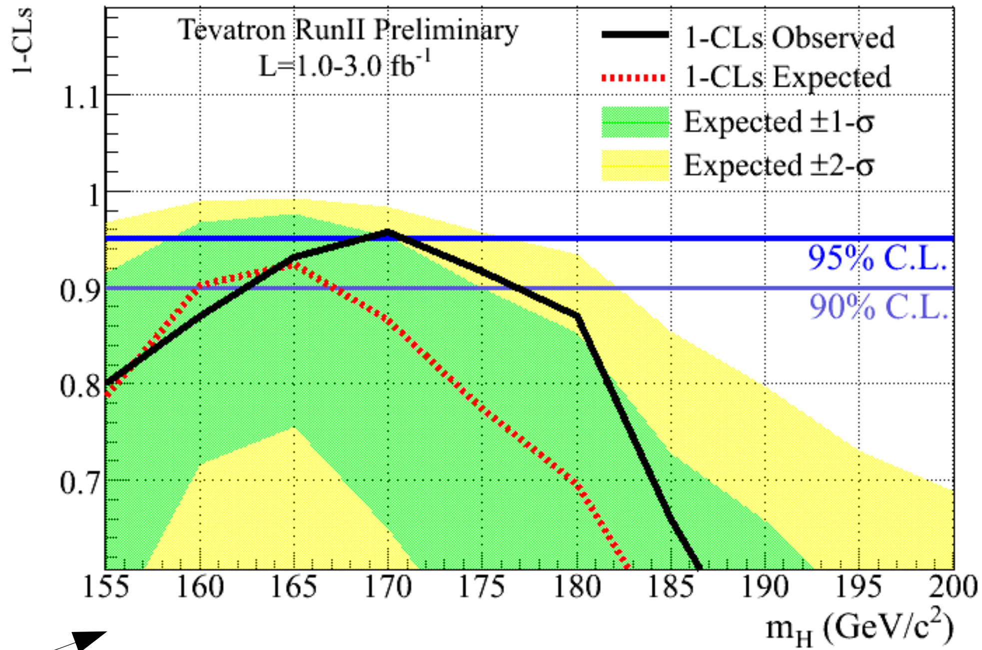


CDF VH-> MET + jets candiate

In a race, the quickest runner can never overtake the slowest, since the pursuer must first reach the point whence the pursued started, so that the slower must always hold a lead.

—Aristotle, Physics





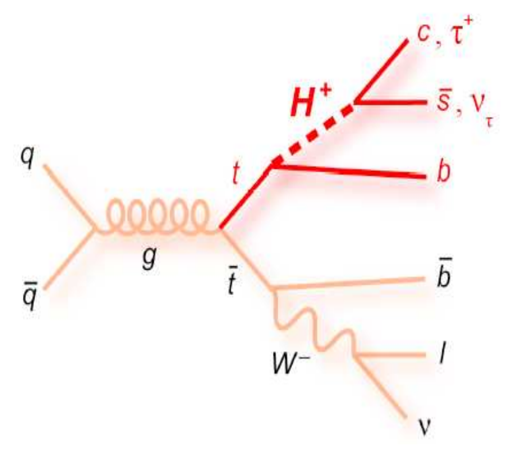
Baysian

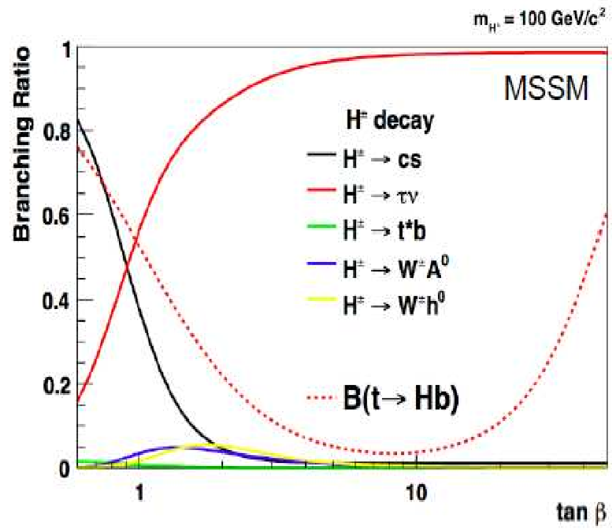
Modified Frequenties (CLs)

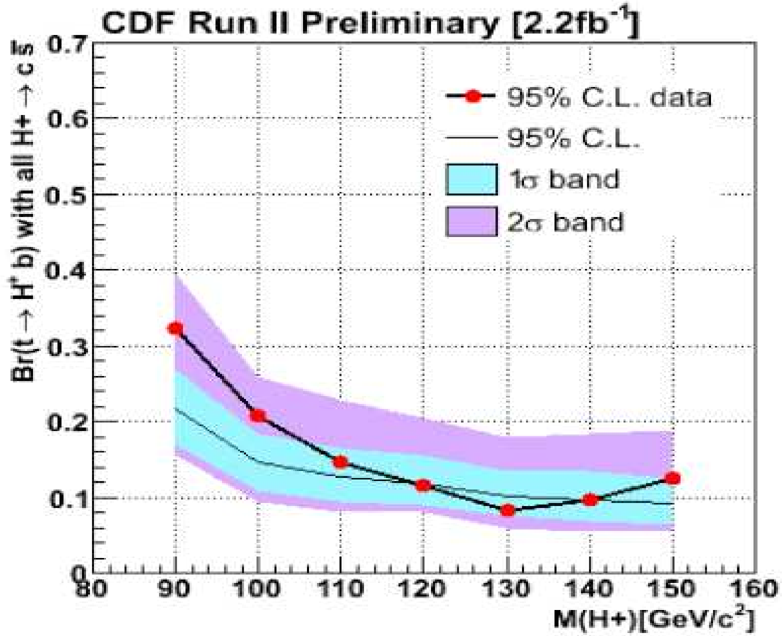
95%CL Limits/SM

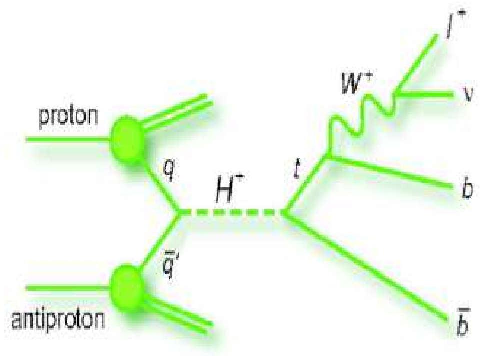
M Higgs(GeV)	160	165	**170**	175
Method 1: Exp	1.3	1.2	1.4	1.7
Method 1: Obs	1.4	1.2	**1.0**	1.3
Method 2: Exp	1.2	1.1	1.3	1.7
Method 2: Obs	1.3	1.1	**0.95**	1.2

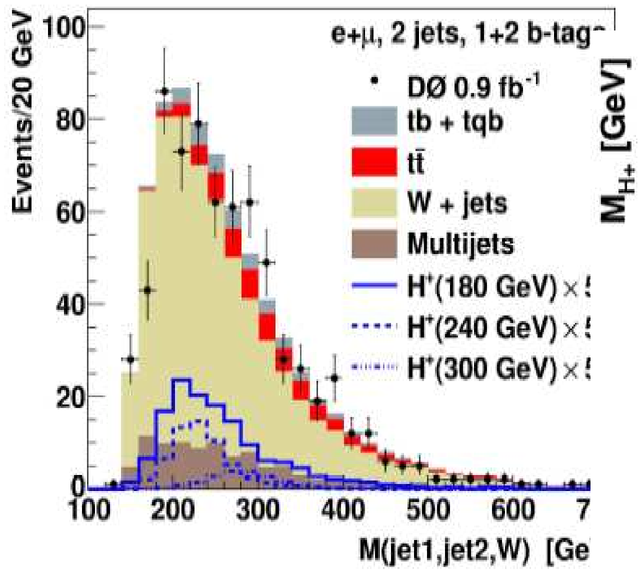
MSSM charged Higgses to and from top

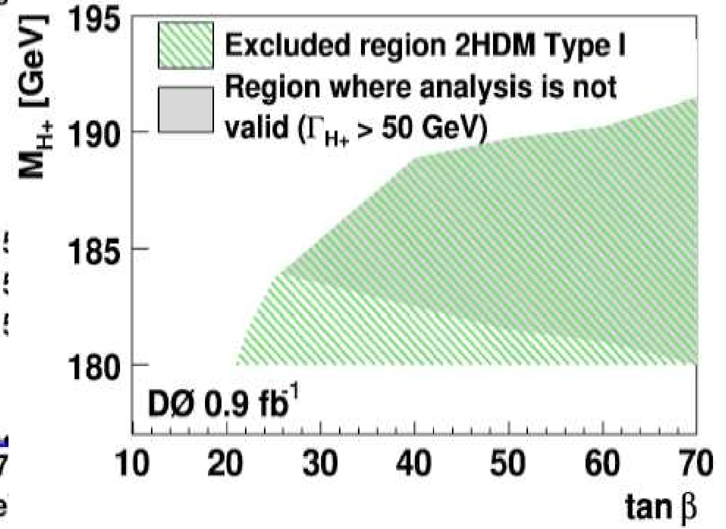












Sensitivity projections